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Simulation Test and Evaluation of TCAS II Logic Version 6.04

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16. Abstract

This paper presents the objectives of the Traffic Alert and Collision Avoidance System II (TCAS II) version 6.04 logic, and the testing and evaluation of it. Described in this paper are the operational problems experienced with its predecessor, version 6.0, along with the modifications that address them. In addition to the testing and evaluation process, performance measures are described. Performance of the two logic versions were compared using simulations of encounters derived from ground radar data from eleven U.S. locations.

The two major goals in comparing the logic versions were the following:

- Obtain an assessment of the effectiveness of the changes on the collision avoidance capability.
- Characterize the effect of the changes on ATC.

The test and evaluation showed that TCAS II version 6.04 logic appears to be operating properly with no adverse effects on any unaltered portions of the logic. That is, no errors were introduced by version 6.04.

Operationally, results of simulations show that the new logic features appear to be very effective in reducing alert rates and displacements. Specifically, unnecessary Traffic Advisories and Resolution Advisories in critical phases of flight were reduced. Resolution Advisories issued at low altitude and on parallel approach were reduced dramatically. The "bump-up" phenomenon was substantially reduced. Unnecessary displacements against legally separated VFR traffic were reduced as well. These four enhancements contribute to making TCAS considerably more compatible with the ATC environment.

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EXECUTIVE SUMMARY

INTRODUCTION

The Traffic Alert and Collision Avoidance System II (TCAS II) Transition Program (TTP) was conducted to provide an early assessment of how the current TCAS II collision avoidance system (CAS) logic performed in wide deployment. Based on feedback solicited from airline pilots and air traffic controllers, there was strong evidence that too many TCAS alarms were issued prematurely and unnecessarily. It was determined that the current logic needs to be better matched to the Air Traffic Control (ATC) operating environment.

CAS logic changes were proposed to substantially reduce these excess alarms and make TCAS more compatible with the ATC operating environment. A new logic package, version 6.04 (v6.04) was, therefore, developed. Logic changes were limited to relatively uncomplicated, but adequate, fixes that could be implemented in a timely fashion, with more extensive modifications deferred for inclusion in future changes.

The test and evaluation (T&E) of this package was performed primarily by computer simulation using a database of radar-constructed encounters. The scope of the T&E effort was to compare the operational characteristics of the new logic (v6.04) to the previous logic (v6.0). Analysis of TCAS performance based on these simulations provided an operational characterization of advantages and disadvantages of the new logic. In addition, contrived encounters were generated to characterize the protection volume of the new logic. Many encounters of varying geometries were used in this T&E process.

IDENTIFYING AND ADDRESSING THE OPERATIONAL PROBLEMS

The operation of the TCAS II collision avoidance logic has been observed over the past year, and modifications have been devised to improve its acceptance in the aviation community. Suggested changes to the design of the collision avoidance algorithms are intended to reduce unnecessary Resolution Advisories (RAs) and Traffic Advisories (TAs), to correct a few disclosed logic errors, and to address some more specific problems (figure ES-1).

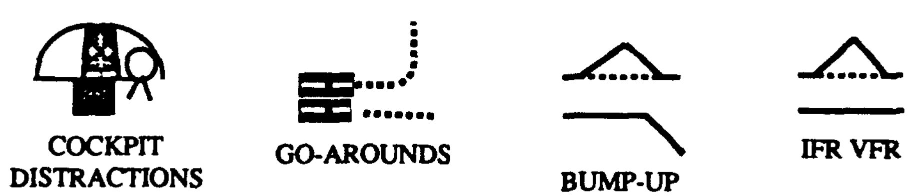


Figure ES-1. Operational Problems with TCAS II Logic Version 6.0 Addressed in Version 6.04

The first problem, which became apparent early in the TTP, involved complaints of distractions caused by unnecessary TCAS RAs during takeoff, landing, and maneuvering in the terminal area. The problem was exacerbated by overly loud cockpit speakers, but the problem itself stemmed from too many RAs and TAs being issued in these flight regimes.

The second problem identified during the TTP was the unnecessary issuance of RAs on parallel approach, especially in visual meteorological conditions (VMC), where closely-spaced parallels are often used. In most cases, these were "Climb" RAs which result in a go-around if the pilot chose to closely adhere to the RA.

The third problem, which is caused by high vertical rate leveloffs, became evident during the TTP primarily at Dallas-Ft. Worth; although, reports of similar encounters were received from various locations around the country, as well as in en route airspace. Positive, displacement-inducing (i.e., "Climb" or "Descend") RAs were issued for level TCAS aircraft against intruders intending to level off 1000 feet before reaching the TCAS aircraft's altitude. Unnecessary displacements of up to 1000 feet were experienced in many cases.

Along the same lines, unnecessary displacements were induced against legally separated, level, Visual Flight Rules (VFR) traffic. These RAs were deemed a nuisance as well, and disruptive to the ATC environment.

The reduction in unnecessary RAs and TAs, in particular due to the problems noted above, is accomplished by reducing thresholds within the logic so that they are more compatible with the ATC environment. Additionally, corrections have been designed to address errors in the display logic and the algorithms for modeling aircraft maneuvers, especially when a TCAS-equipped aircraft is performance limited.

The v6.0 logic principally suffered from too strict thresholds, and a lack of variability of thresholds at low altitudes (below 5000 feet). Based on v6.0, several of the detection and resolution parameters used in issuing and selecting the severity of alarms were adjusted for v6.04. In addition, the scheme used for desensitizing TCAS was modified slightly to incorporate more layers, allowing more variety for operation at low altitudes. Figure ES-2 provides a graphical representation of the v6.0 layers and the corresponding thresholds, and figure ES-3 shows the same information for v6.04.

SIMULATION TESTING

The simulation test facility was developed for the purpose of simulating the operation of the CAS logic using radar data from various sources. A combination of microcomputers and mainframes are used in the test facility; however, the majority of the software resides on an IBM mainframe. This software was verified and is currently under strict configuration control.

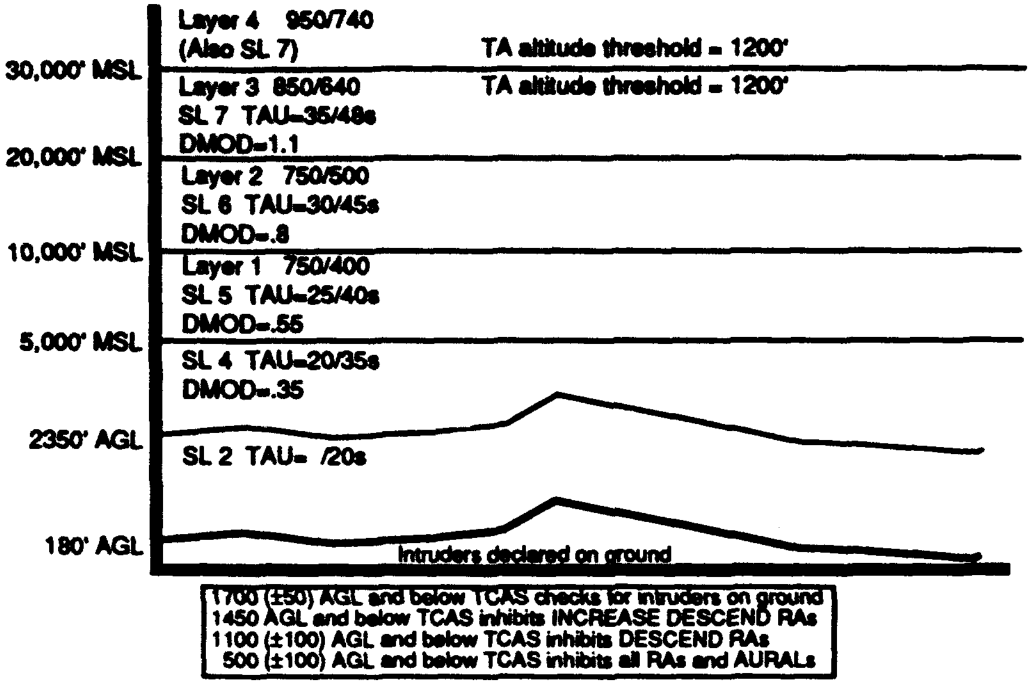


Figure ES-2. Version 6.0 Logic Thresholds

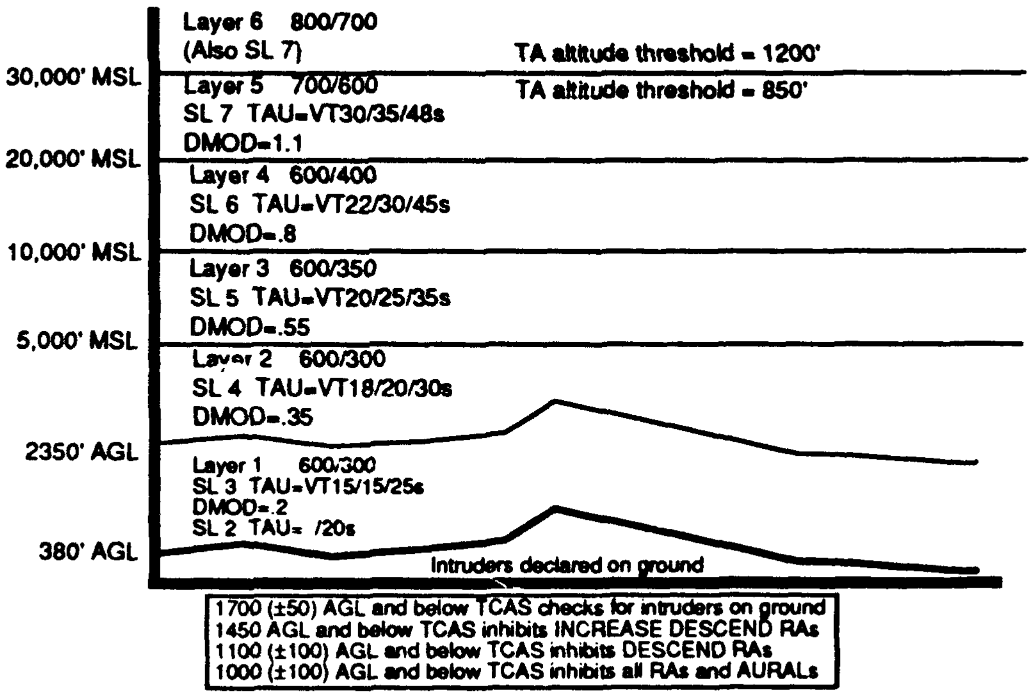


Figure ES-3. Version 6.04 Logic Thresholds

The first goal of the simulation test and evaluation process was to obtain an assessment of the effectiveness of the changes on the collision avoidance capability, and to determine if the revised logic provided sufficient protection. The assessment was based on the performance of the revised logic, v6.04, as compared to the unrevised logic, v6.0. Reductions in the number of RAs and displacements for v6.04 versus v6.0 were noted; however, a determination was made for those encounters in which RAs were eliminated whether adequate separation was maintained. Additionally, a determination was made for those encounters in which RAs were still issued (by v6.04), whether advisories were still appropriate and timely. A large number of highly varied encounter geometries were used to make these determinations.

The second goal of testing was to characterize the interaction of TCAS with ATC in typical operations. More specifically, the following objectives were established:

- To determine if TCAS is issuing excessive or unnecessary alerts during typical operations (i.e., are there any "hot spots"?)
- To ensure that a fair cross-section of airspace operations are analyzed
- To resolve whether v6.04 is effective in addressing ATC concerns about go-arounds, bump-ups, and displacements

Performance of the two logic versions were compared using simulations of encounters derived from ground radar data from eleven U.S. locations (see figure ES-4). These locations cover a wide range of densities and operations throughout the country. Hundreds of hours of data collected were used to generate the data base of encounters. Logic test simulations were run on more than 4000 of these Automated Radar Terminal System (ARTS) derived encounters. In the simulation, each encounter involved a pair of aircraft tracks with one aircraft equipped with TCAS and the other unequipped, and was run ten times with randomly jittered position and pilot response inputs.

RESULTS AND CONCLUSIONS

The test and evaluation showed that the TCAS II v6.04 logic appears to be operating properly with no adverse effects on any unaltered portions of the logic. That is, no errors were introduced by v6.04.

The characteristics of the operational performance noted in the TTP are most easily seen by a multidimensional chart, as illustrated in figure ES-5, where the dark bars are v6.0 and the white bars are v6.04. With the new logic there are fewer RAs issued (preventive and corrective). This varies from about 30 percent in Ontario to about 75 percent in St. Louis. In addition, at Dallas-Ft. Worth, preventive RAs were issued one out of every four times (25 percent) for v6.0, but only one out of eight times (12 percent) for v6.04. At all locations, the percentage of preventive RAs went down for v6.04, showing that the RAs retained were more predominantly corrective and necessary.

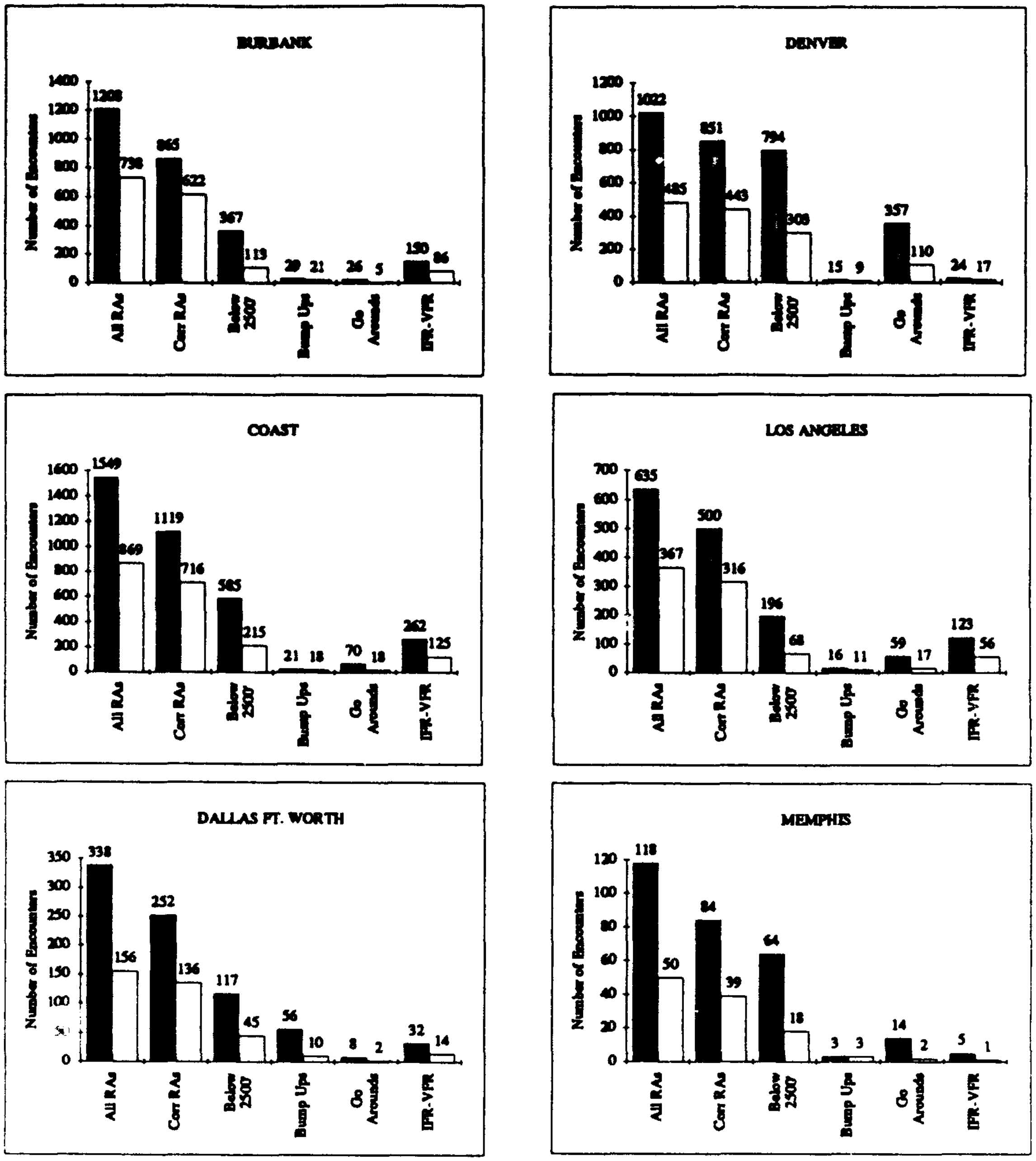


Figure ES-5. Overall Benefits from v6.04 at All Locations

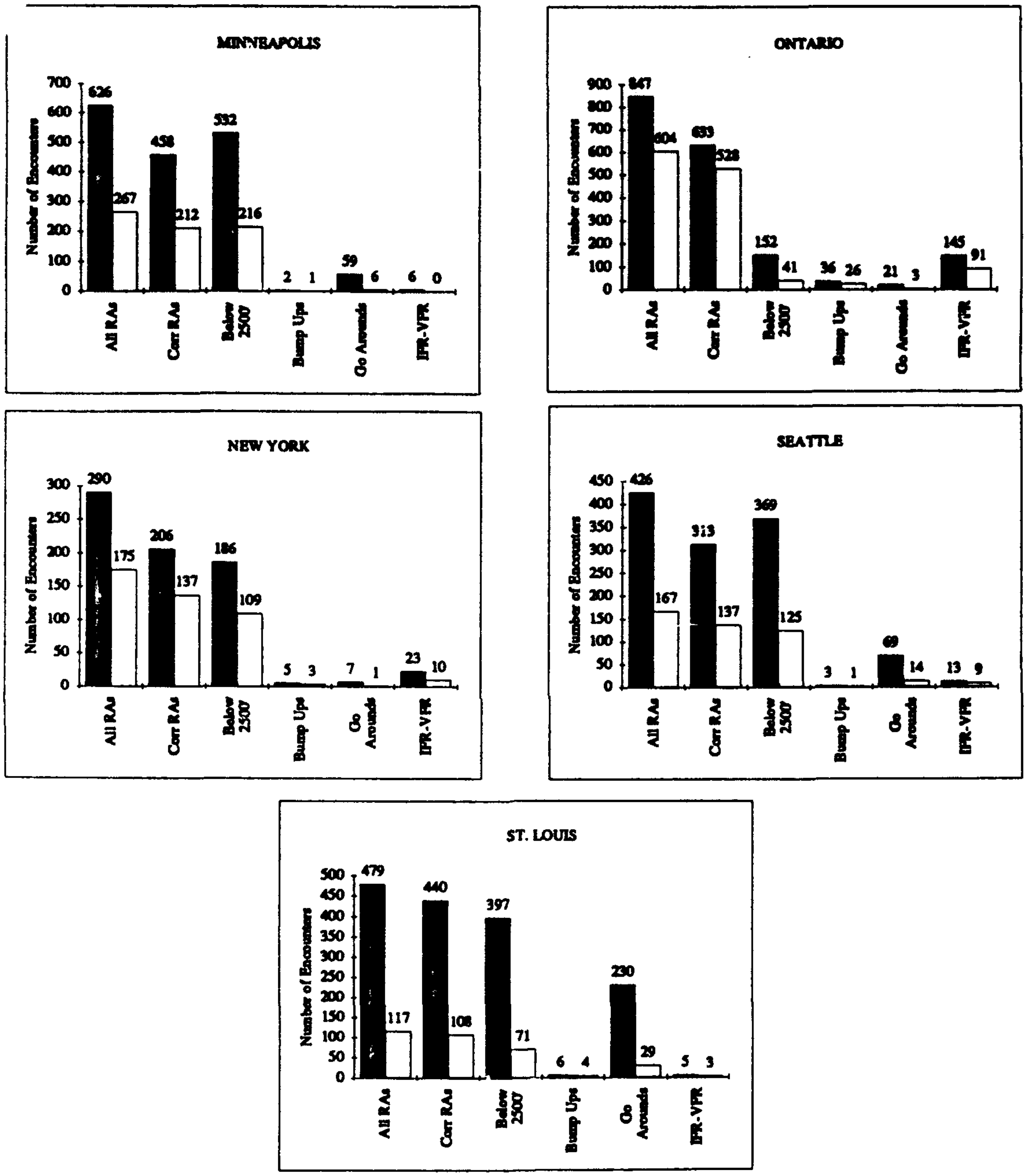


Figure ES-5. Overall Benefits from v6.04 at All Locations (Concluded)

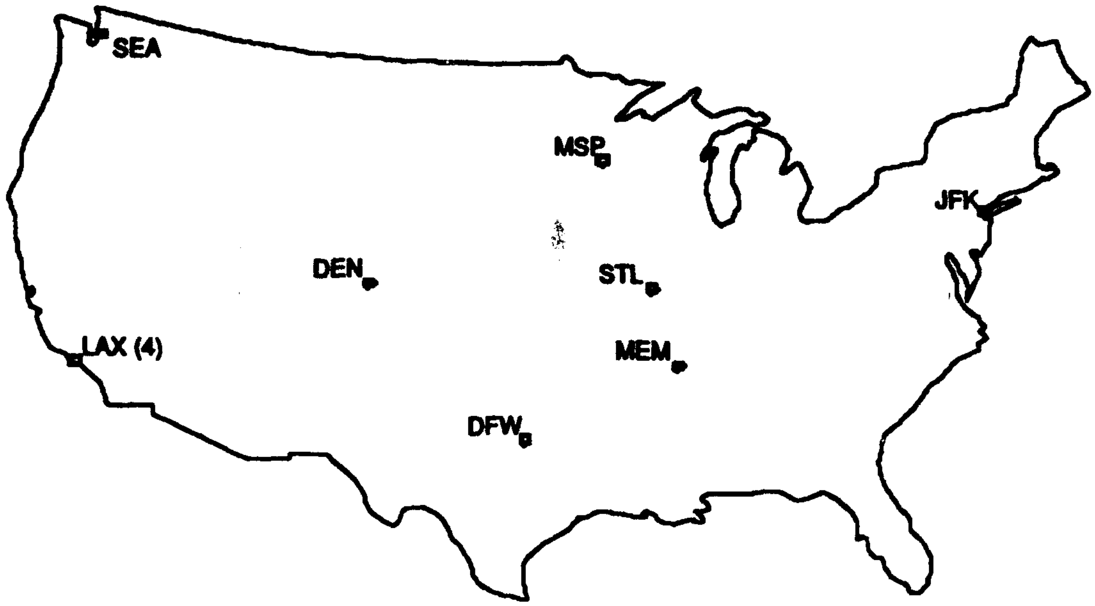


Figure ES-4. Location of ARTS Data Collection Sites

RAs (preventive and corrective) that occurred below 2500 ft above ground level (AGL), at most sites, constituted a substantial portion of the total. The improvement seen for Dallas-Ft. Worth is typical of that seen at most of the sites for v6.04; however, at New York the improvement was less striking.

The bump-up occurs when a TCAS-equipped aircraft is level, the intruder is climbing or descending toward it, intending to level off 1000 feet away. A positive, displacement-inducing "Climb" or "Descend" RA forces the TCAS-equipped aircraft several hundred feet away from its original altitude. The reduction in the number of bump-ups at Dallas-Ft. Worth is striking; although, at most other locations there was some improvement as well.

In an attempt to evaluate the effectiveness of the new logic in minimizing TCAS-induced go-arounds, results of the simulations were examined for corrective RAs in which both aircraft were below 3000 ft AGL and descending, and a "Climb" RA was issued. Encounters of this type were identified at Los Angeles, Memphis, Minneapolis, Seattle, and especially St. Louis (nearly half of the locations), and improvements were substantial at these locations.

Encounters involving two aircraft that were level and separated by approximately 500 feet (± 50 ft.), and for which a positive, displacement-inducing "Climb" or "Descend" RA was issued, were observed at Burbank, Coast, Dallas-Ft. Worth, Los Angeles, New York, and Ontario—about half of the sites. Like the bump-up, this type of RA forces a level, TCAS-

equipped aircraft away from its clearance. As exemplified in the last pair of bars in figure ES-5, for Dallas-Ft. Worth, the new logic reduced the occurrence of these RAs to about one-half of its previous value.

The testing provided an extensive understanding of the operation of TCAS Version 6.04 in all airspace. The end product of the T&E was a version of the CAS logic that still provided effective separation, while having a significant reduction in the frequency of unnecessary alarms. To recap the specific advantages of the v6.04 logic, the following points can be made from the simulation results of ARTS-derived encounters:

- With the new logic there are fewer RAs (preventive and corrective). The overall reduction in the number of RAs issued varies from 30 percent in Ontario to about 75 percent in St. Louis.

- At all locations, the percentage of preventive RAs went down for v6.04, showing that the RAs retained were predominantly corrective and necessary.

- RAs issued below 2500 feet AGL at most sites constituted a substantial portion of the total. Reductions were seen at most of the sites; however, at New York the improvement was less noticeable.

- The reduction in the number of "bump-ups" at Dallas-Ft. Worth is striking, and at most other locations there was some improvement as well.

- Go arounds on approach due to v6.0 RAs were identified at nearly half of the locations, and improvements were substantial at these locations for v6.04.

- The new logic reduced the occurrence of displacements against legally separated VFR traffic by about 50 percent.

- For all locations, separation at Closest Point of Approach (CPA) for encounters no longer resulting in an RA with v6.04 appears to be adequate.

- For all locations, achieved separation at CPA based on proper response to v6.04 RAs appears to be adequate.

- Large vertical displacements experienced due to RA responses will be substantially less for v6.04 than for v6.0.

- Most v6.04 RAs are issued when the two aircraft are within nominal Instrument Flight Rules (IFR) ATC separation standards (i.e., less than 1000 feet away vertically and less than three miles horizontally, or five miles at higher altitudes).

The enhancements contained in v6.04 of the TCAS II logic contribute to making TCAS considerably more compatible with the ATC environment, provide a TCAS logic that is about half as intrusive as v6.0, and result in a substantial improvement in the quality of the system.

SECTION 1

INTRODUCTION

The Traffic Alert and Collision Avoidance System II (TCAS II) Transition Program (TTP) was conducted to provide an early assessment of how the current TCAS II collision avoidance system (CAS) logic version 6.0 (v6.0) performed in wide deployment. Based on feedback solicited from airline pilots and air traffic controllers, there was strong evidence that too many TCAS alarms were issued prematurely and unnecessarily. It was determined that the current logic needs to be better matched to the Air Traffic Control (ATC) operating environment.

CAS logic changes were proposed to substantially reduce these excess alarms and make TCAS more compatible with the ATC operating environment. A new logic package (version 6.04 [v6.04]) was, therefore, developed. Logic changes were limited to relatively uncomplicated, but adequate, fixes that could be implemented in a timely fashion, with more extensive modifications deferred for inclusion in future changes.

This report documents the test and evaluation (T&E) of this package, which was performed primarily by computer simulation using a database of radar-constructed encounters. The scope of the T&E effort was to compare the operational characteristics of the new logic (v6.04) to the previous logic (v6.0). (In a companion report (reference 1), the system safety implications of the new logic are examined.) Analysis of TCAS performance based on these simulations provided an operational characterization of advantages and disadvantages of the new logic. In addition, contrived encounters were generated to characterize the protection volume of the new logic. Many encounters of varying geometries were used in this T&E process.

This report is organized in the following manner: section 2 presents the goals for a better TCAS II, which were determined by identifying and addressing the operational problems discovered during the TTP. Section 3 describes the software and verification of the simulation test facility. Section 4 presents the scope and approach used for the test and evaluation of CAS logic v6.04 versus v6.0. The scenarios used for testing, and the operational features tested are described as well. Section 5 presents the results of testing v6.04 using encounters derived from the Automated Radar Terminal System (ARTS) from a variety of sites throughout the United States. Finally, section 6 summarizes the conclusions drawn from this process.

SECTION 2

GOALS FOR A BETTER TCAS II

The operation of the TCAS II collision avoidance logic has been observed over the past year, and modifications have been devised to improve its acceptance in the aviation community. Suggested changes to the design of the collision avoidance algorithms are intended to reduce unnecessary Resolution Advisories (RAs) and Traffic Advisories (TAs), and to correct a few disclosed logic errors. The reduction in unnecessary RAs and TAs is accomplished by reducing thresholds within the logic so that they are more compatible with the ATC environment. Additionally, corrections have been designed to address error in the display logic and the algorithms for modeling aircraft maneuvers, especially when a TCAS-equipped aircraft is performance limited. The following section presents the operational problems that have been identified, and which are addressed in v6.04.

2.1 IDENTIFYING THE OPERATIONAL PROBLEMS

To some degree in previous operational evaluations of TCAS II, and especially during the TTP, several operational problems were highlighted. The first problem, which became apparent early in the TTP, involved complaints of distractions caused by unnecessary TCAS RAs during takeoff, landing, and maneuvering in the terminal area. The problem was exacerbated by overly loud cockpit speakers, but the problem itself stemmed from too many RAs and TAs being issued in these flight regimes. Figure 1 below depicts this problem.

The second problem identified during the TTP was the unnecessary issuance of RAs on parallel approach, especially in visual meteorological conditions (VMC), where closely-spaced parallels are often used. In most cases, these were "Climb" RAs which result in a go-around if the pilot chose to closely adhere to the RA. Figure 2 depicts the situation graphically.

The third problem, which is caused by high vertical rate leveloffs, became evident during the TTP primarily at Dallas-Ft. Worth; although, reports of similar encounters were received from various locations around the country, as well as in en route airspace. Positive, displacement-inducing (i.e., "Climb" or "Descend") RAs were issued for level TCAS aircraft against intruders intending to level off 1000 feet before reaching the TCAS aircraft's altitude, as shown in figure 3. Unnecessary displacements of up to 1000 feet were experienced in many cases, due in part to over enthusiastic pilot response, but primarily due to long positive RAs.

Along the same lines, unnecessary displacements were induced for instrument flight rules (IFR) against legally separated, level, visual flight rules (VFR) traffic as depicted in figure 4. These RAs were deemed a nuisance as well, and disruptive to the ATC environment.

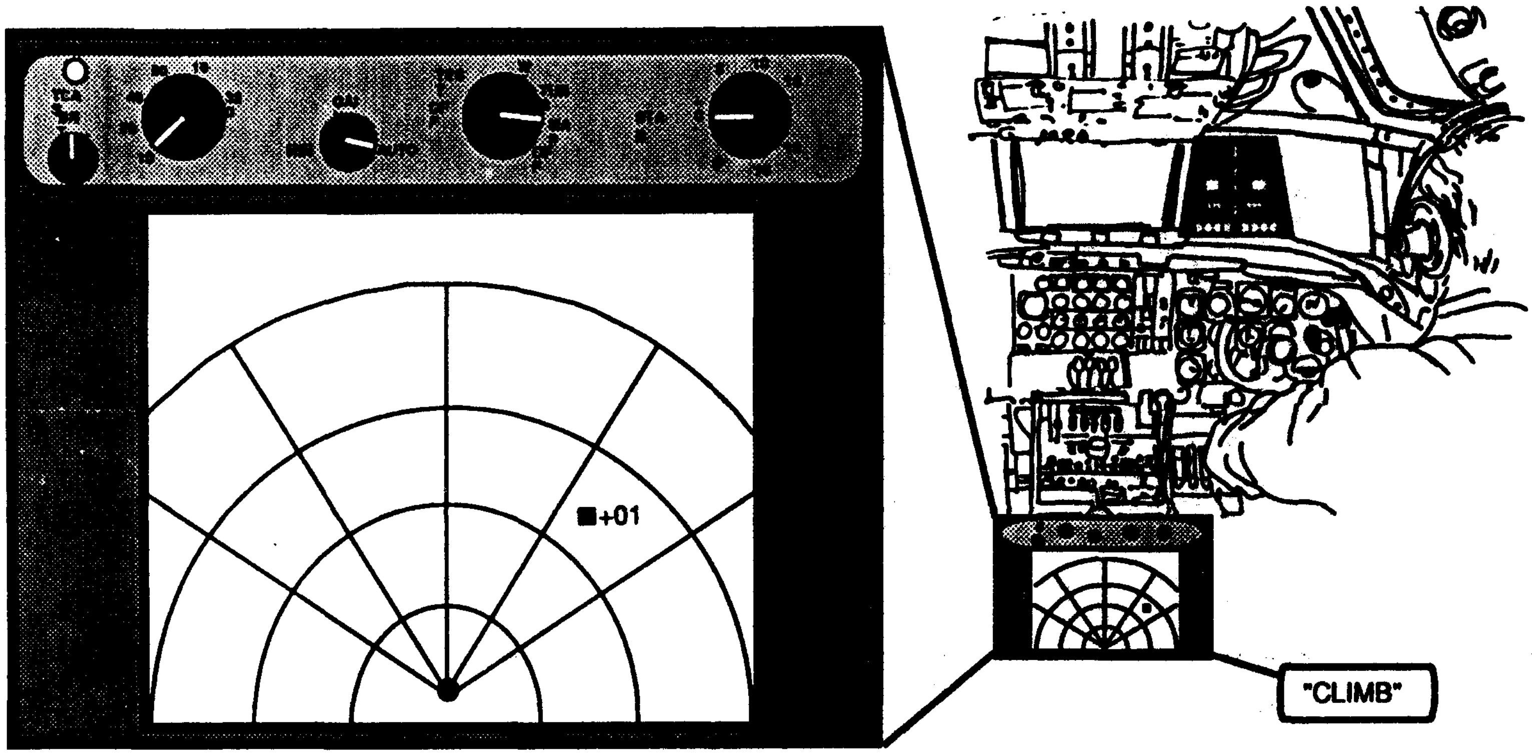


Figure 1. Cockpit Distractions During Critical Phases of Flight

Cockpit distractions were highlighted by the pilots because TCAS was issuing unnecessary RAs and TAs, especially in the takeoff and landing phases of flight. The CAS logic appeared to be too sensitive in these regimes. The thresholds needed to be reduced so that fewer alarms would be generated, making TCAS more transparent.

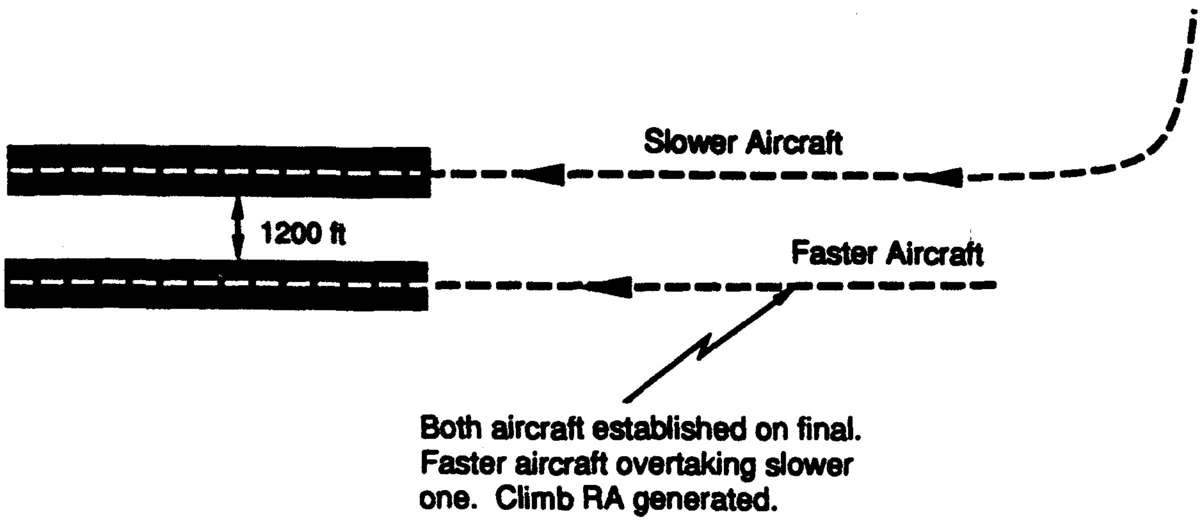


Figure 2. Unnecessary RAs on Parallel Approach and RAs That Result in Go-Arounds

During parallel approach, TCAS II will often issue an RA to one or both aircraft simply because of their proximity, slight undulations in course, or relative speed (one aircraft overtaking another as depicted above). The logic thresholds are too large for the close proximity on parallel approach, and if the TCAS unit is not manually switched to TA-only mode, an RA will occur in many cases. If the RA is a "Climb", a go-around may be necessary if the pilot responds appropriately to it.

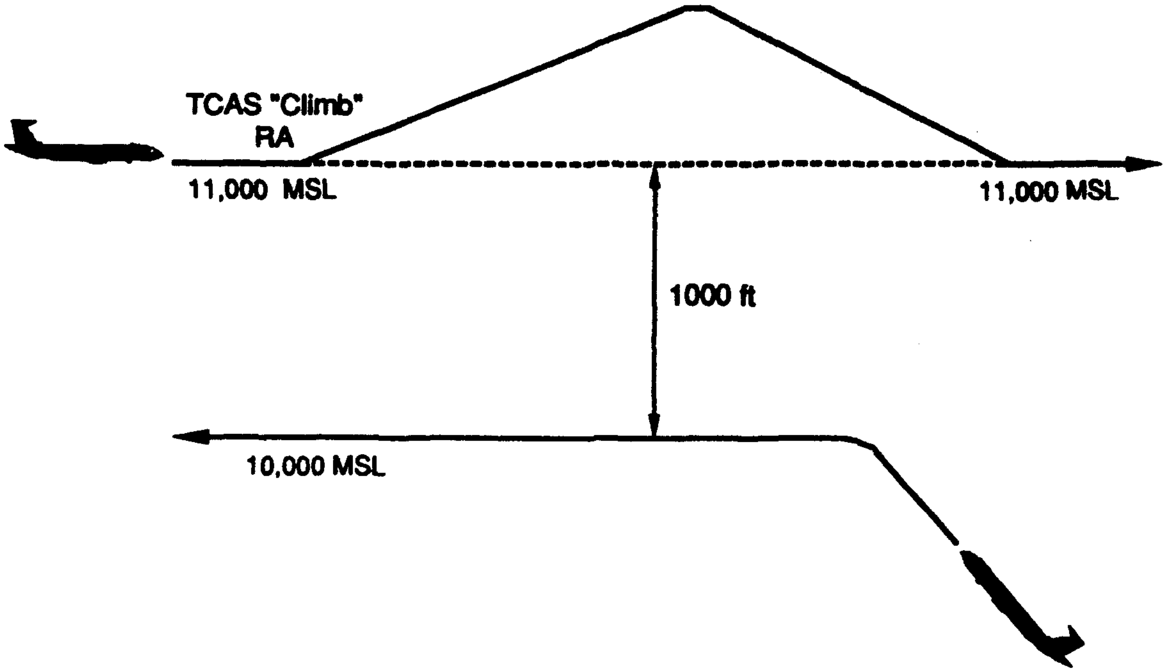


Figure 3. The "Bump-up" Phenomenon

The "Bump-up" phenomenon (being pushed off altitude by a positive RA due to a high vertical rate intruder) was identified by both pilots and controllers as unacceptable. Of concern in these encounters was the early issuance of a "Climb" or "Descend" RA to the aircraft in level flight, the long duration of this advisory, and the resulting altitude displacement (often by many hundreds of feet) from its cleared altitude.

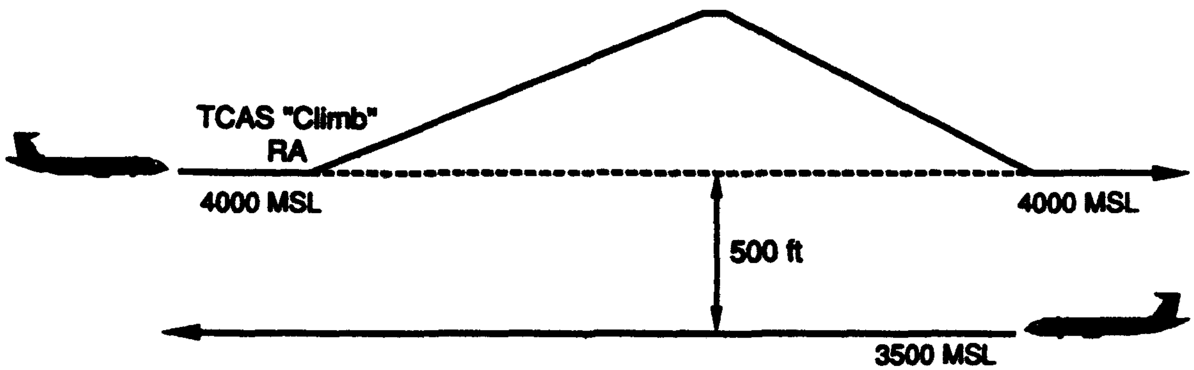


Figure 4. Displacement Against Legally Separated VFR Aircraft

IFR-VFR separation standards allow 500 feet of vertical separation between level IFR and VFR aircraft, while TCAS II requires at least 500 feet of separation between two level aircraft in certain altitude regimes (otherwise, it will issue a positive, displacement-inducing RA). It is inappropriate for TCAS thresholds to be that conservative.

Some of these problems were identified during normal operation of TCAS II over the past three years, but their influence on degrading the confidence of pilots and controllers in the system was highlighted in the TTP. The following section describes in greater detail the modifications to the collision avoidance logic that address these problems.

2.2 ADDRESSING THE OPERATIONAL PROBLEMS

The two CAS logic modules that govern the issuance, timing, strength, and effectiveness of a TCAS RA are Detection and Resolution. These modules were therefore identified as the portions of the CAS logic to modify in order to address the operational problems. Appendix A provides a list of Problem/Trouble Reports (PTRs) and Change Request Forms (CRFs) addressed in v6.04, and a detailed statement on the justification and rationale for all of the logic modifications described in this section.

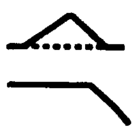
COCKPIT DISTRACTIONS

One feature of the Detection module is to "turn off" or inhibit RAs below an appropriate altitude when they are undesirable very close to the ground. This feature assists in reducing cockpit distractions during a critical flight regime. It also reduces the occurrence of a go-around induced by a TCAS RA at very low altitudes. For these reasons, the altitude below which RAs are inhibited was raised from 500 to 1000 ft. TA alarm thresholds were also relaxed in v6.04, with the intent of further reducing cockpit distractions.


GO-AROUNDS

Another feature of the Detection module includes the criteria for threat detection at low altitudes. These criteria are the TAU and DMOD thresholds. To make TCAS less disruptive in the lower flight regime, these thresholds were reduced. The Resolution module also contains logic to select the strength of an RA. The threshold that determines whether a positive, displacement-inducing (i.e., "Climb" or "Descend") RA will be issued is the value of the altitude limit (ALIM), and it too was reduced. These changes were identified in order to minimize RAs at low altitudes, and to further reduce the occurrence of RAs resulting in go-arounds on approach.

In order to minimize unnecessary RAs (especially at low altitudes) and excessive RA-induced altitude displacements, a new scheme providing for six (instead of four) altitude layers was designed, so that the values for ALIM, TAU, and DMOD thresholds could be more appropriately tailored to operations at lower altitudes. Reductions in ALIM were also considered. Simulations were run and studies performed with different ALIM values to reduce the number of positive, displacement-inducing RAs while still maintaining adequate separation, and taking into account altimetry error and other errors. The results of this study indicated new values to be set at {300, 300, 350, 400, 600, 700} over six regions in place of {400, 500, 640, 740} over four regions. [The values for the first two regions in the new scheme are the same at this time; however, the use of the additional altitude layer provides for possible later modifications of the thresholds when own aircraft is close to the ground.]


BUMP-UP

A third feature of the Detection module is the assumption that an intruder will continue along its same path for the next half minute or so. For an intruder with a high vertical rate that is intending to level off about 1000 feet away vertically, this means that an RA could be issued when the intruder is still well separated from its leveloff altitude, resulting in unnecessary and sometimes excessive vertical displacements by the TCAS aircraft. This problem can be addressed effectively by deferring the issuance of the RA long enough so that the leveloff can be detected, thus obtaining a much more accurate estimate of the true vertical miss at closest point of approach (CPA). The Vertical Threshold Test (VTT) accomplishes this by using reduced values of the Altitude Threshold (ZTHR) and reduced values of the vertical TAU threshold that are only applied in certain encounter geometries. Reductions in these thresholds were limited so that the nominal ALIM separation can still be achieved if the intruder does not level off.


IFR VFR

Reductions in ALIM also serve to alleviate the problem of positive, displacement-inducing ("Climb" or "Descend") RAs issued against legally separated VFR traffic.

In summary, based on v6.0, several of the detection and resolution parameters used in issuing and selecting the severity of alarms were adjusted for v6.04. In addition, the scheme used for desensitizing TCAS was modified slightly to incorporate more layers, allowing more variety

for operation at low altitudes. Figure 5 provides a graphical representation of the v6.0 layers and the corresponding thresholds, and figure 6 shows the same information for v6.04.

Vertical Threshold Test

In selecting new ZTHR values (the altitude threshold for threat detection), an analysis was conducted to determine a more acceptable value. Encounters were simulated using high vertical rate leveloff geometries, in which one aircraft is level and the other aircraft has vertical rates ranging from 2500 to 6000 fpm, leveling off approximately 1000 feet away with an acceleration ranging from .05g to .33g. As the value of ZTHR was reduced, the number of RAs issued for one or the other aircraft decreased but the rate of decrease was significantly less for ZTHR < 600 feet. The number of corrective RAs also followed this pattern. This study contributed to the selection of a new set of ZTHR values.

A similar study was conducted for selecting an appropriate value for the vertical TAU threshold to be used by the VTT. Again, the number of RAs decreased steadily for values of vertical TAU tested, and an optimum was selected accordingly. (The VTT TAUV values were chosen to achieve a targeted separation of ALIM feet in an encounter where the threat is projected to be coaltitude and does not level off.) These moderate reductions are not applied in those encounters where own aircraft has the higher rate or a rate opposite that of the intruder. Those geometries require the larger thresholds to obtain the desired separation.

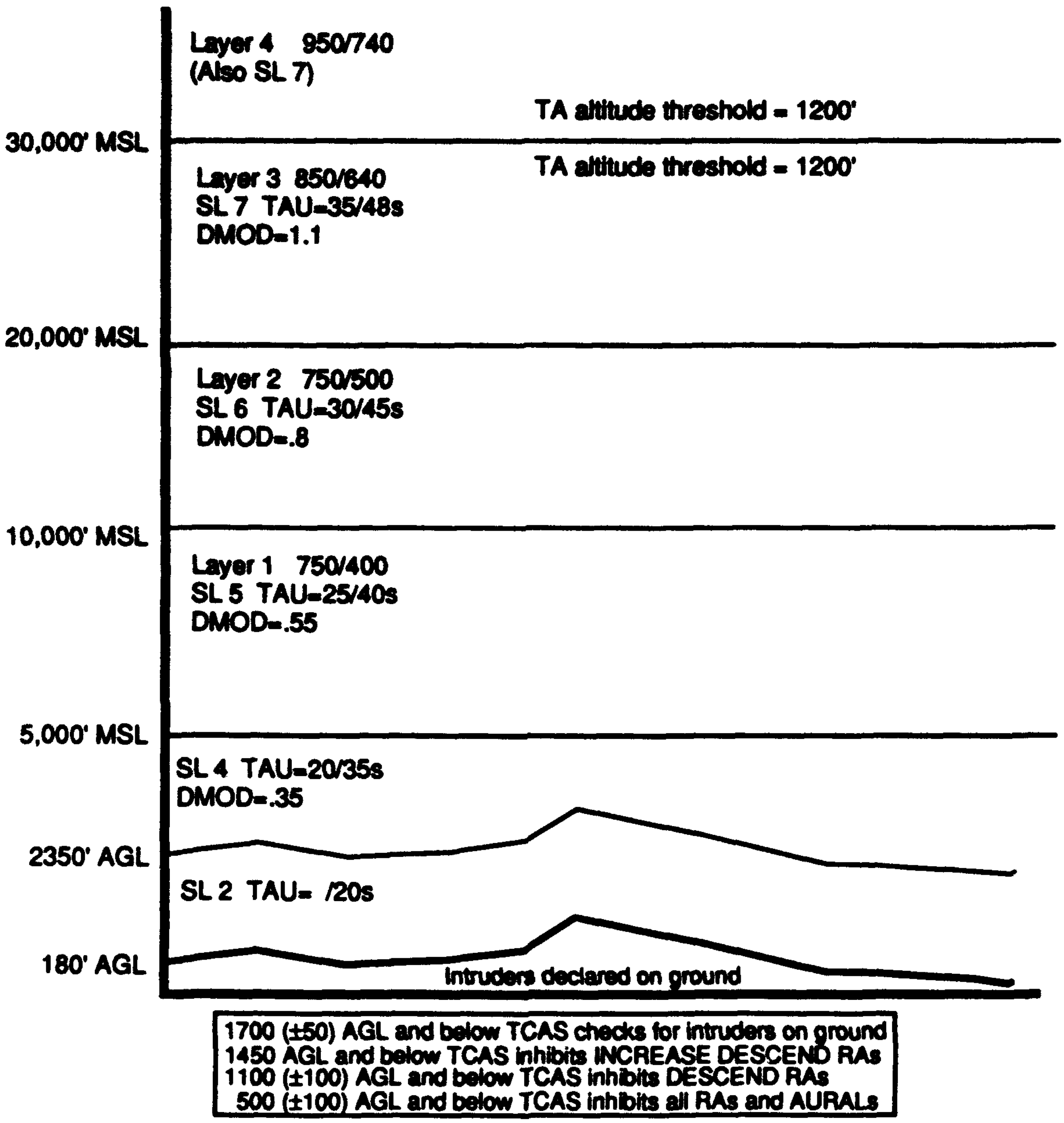


Figure 5. Version 6.0 Thresholds

Version 6.0 principally suffers from too strict thresholds, and a lack of variability in thresholds at low altitudes (below 5000 feet).

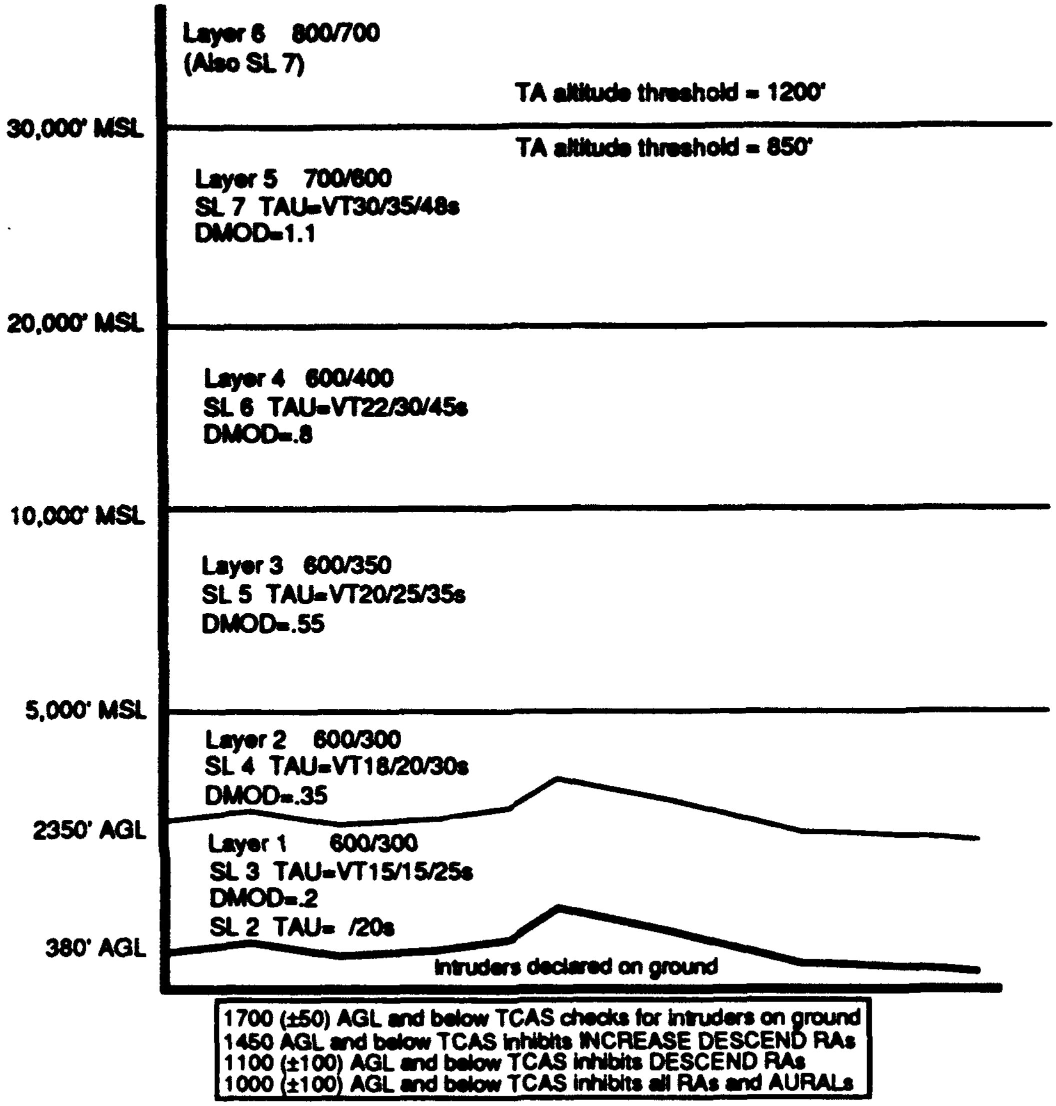


Figure 6. Version 6.04 Thresholds

Version 6.04 provides six altitude layers for more specificity in thresholds at low altitudes. The values for ZTHR and ALIM are indicated following the layer numbers. Seven sensitivity levels are provided, with modified VTT TAU, normal range and vertical TAU, and TA TAU threshold values. The new values for DMOD are provided in each sensitivity level as well. Note that the TA altitude threshold is set to 850 feet below Flight Level (FL) 300. The intruder on ground altitude was raised to 380 feet (with hysteresis). The box at the bottom of the figure provides the altitude thresholds (with hysteresis) for the enabling of the intruder on ground logic, followed by the altitude inhibits for the Increase Descend RA, the Descend RA, all RAs, and aurals.

SECTION 3

THE SIMULATION TEST FACILITY

The simulation test facility was developed for the purpose of simulating the operation of the CAS logic using radar data from various sources. A combination of microcomputers and mainframes are used in the test facility; however, the majority of the software resides on an IBM mainframe. This software was verified and is currently under strict configuration control. Figures 7 and 8 describe the data flow and operation of the simulation test facility.

For verifying the core of the simulation, the software implementation of the actual CAS logic, a simulation walkthrough was conducted. The purpose of the walkthrough was to obtain a baseline for configuration management and to ensure that the CAS logic was implemented properly based on the Minimum Operational Performance Standards (MOPS) pseudocode v6.0 and v6.04. After detailed PL/I code walkthroughs were conducted to verify that the software was an accurate reflection of the pseudocode, the baseline software test configuration was established and placed under configuration control.

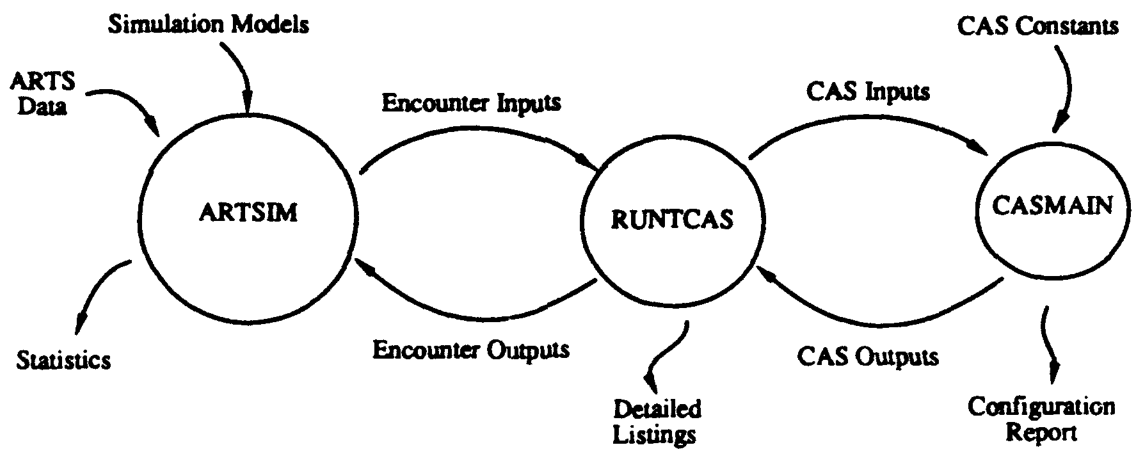


Figure 7. Data Flow for the Simulation Software

The inputs to the simulation are the ARTS data, the simulation models, and the CAS constants. The analysis layer, implemented as ARTSIM, generates as output encounter statistics (which describe the encounter geometry) and encounter inputs for the encounter layer, RUNTCAS. RUNTCAS exercises the CAS layer, CASMAIN, by sending it the CAS inputs and receiving back from it CAS outputs. (CASMAIN uses the proper CAS constants and generates a configuration report of the CAS logic version it executed.) RUNTCAS provides encounter outputs back to ARTSIM for use in formulating the encounter statistics, and generates detailed listings describing the results of the performance of the CAS logic during that encounter.

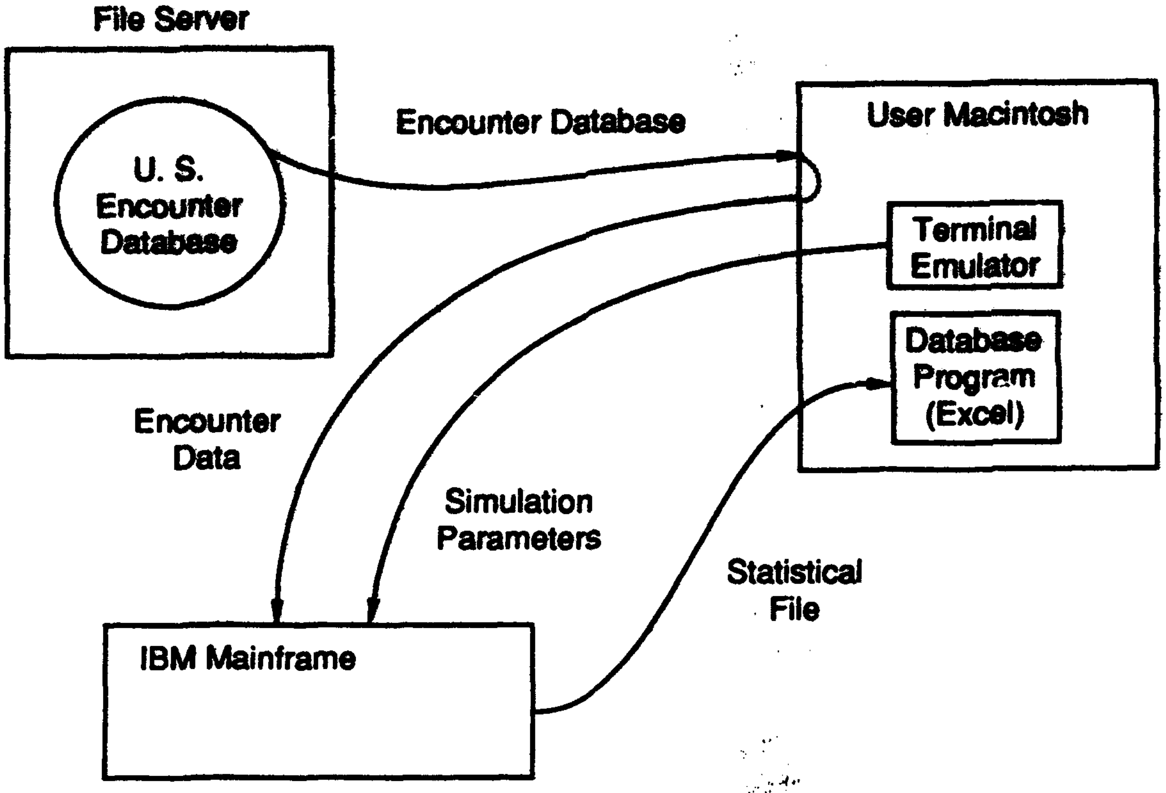


Figure 8. Running ARTS Encounters

The U.S. database containing ARTS-derived encounters is accessed via a local area network, and personal computers (PCs) are used as terminal emulators to access the simulation software on an IBM mainframe computer. Output from the simulation is downloaded to the PCs and processed using commercial packages available for data processing, worksheets, and charting such as Microsoft Excel. Charts provided in the appendices were prepared using Excel.

Specific "white box tests" were developed with the purpose of checking the internal operation of collision avoidance logic, housekeeping, intruder, and threat file linkups. This task assisted in gaining assurance that the simulation is a correct implementation of the pseudocode. Figure 9 depicts the types of tests included in this test set. This phase of logic testing involved close scrutiny of every flag and calculated variable to ensure correct CAS logic performance. See appendix B for a list of logic features tested. The end product of this phase of testing was a design and implementation that was verified as being both reliable and correct.

The final step in verifying the test facility was the performance of cross-checks with the TCAS simulation facility at the Federal Aviation Administration (FAA) Technical Center to ensure consistency of test facilities. MOPS bench tests were used as an adequate measure of consistency. Bench test results from the two simulation facilities were compared and discrepancies were resolved.

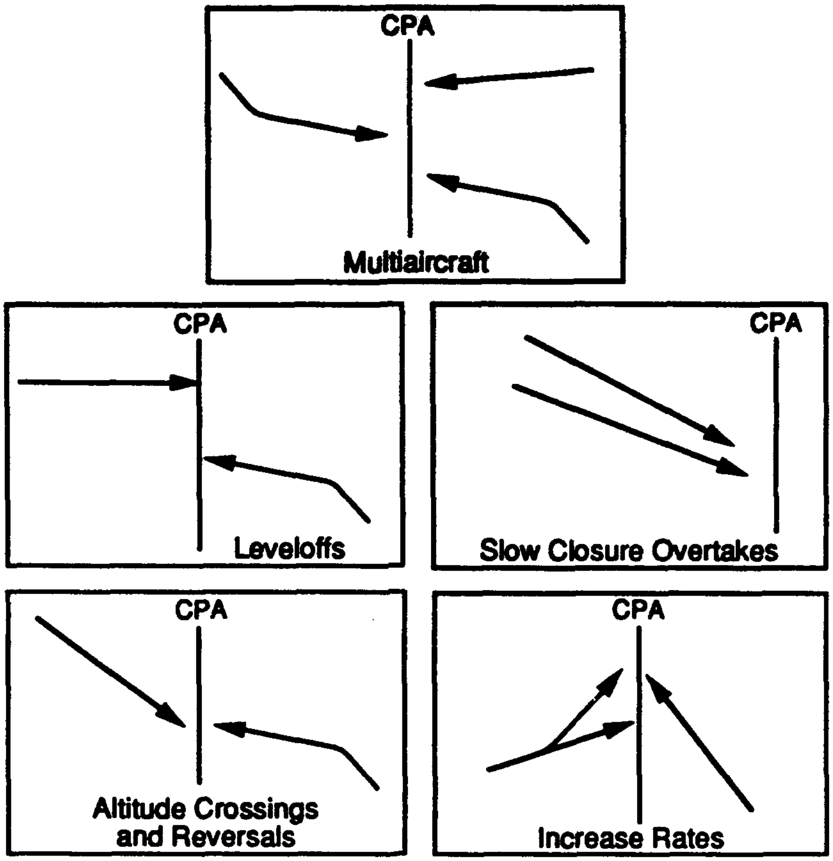


Figure 9. Scenarios Used in Verification

All types of geometries were used as inputs to the v6.04 simulation. Specifically, own and intruder leveloff encounters, multi-aircraft (i.e., more than one intruder), and slow closure overtake geometries were used as contrived scenarios. Other scenarios were contrived to invoke the altitude crossing RA and RA reversal logic, as well as the increase rate RA logic.

SECTION 4

TEST AND EVALUATION OF CAS LOGIC VERSION 6.04 VERSUS VERSION 6.0

The first goal of the test and evaluation process was to obtain an assessment of the effectiveness of the changes on the collision avoidance capability, and to determine if the revised logic provided sufficient protection. The assessment was based on the performance of the revised logic, v6.04, as compared to the unrevised logic, v6.0. Reductions in the number of RAs and displacements for v6.04 versus v6.0 were noted; however, a determination was made for those encounters in which RAs were eliminated whether adequate separation was maintained. Additionally, a determination was made for those encounters in which RAs were still issued (by v6.04), whether advisories were still appropriate and timely. A large number of highly varied encounter geometries were used to make these determinations.

The second goal of testing was to characterize the interaction of TCAS with ATC in typical operations. More specifically, the following objectives were established:

- To determine if TCAS is issuing excessive or unnecessary alerts during typical operations (i.e., are there any "hot spots"?)
- To ensure that a fair cross-section of airspace operations are analyzed
- To resolve whether v6.04 is effective in addressing ATC concerns about go-arounds, bump-ups, and displacements

The following sections describe the specific operational features, the specific objectives, and the scenarios used for the testing and evaluation.

4.1 OPERATIONAL FEATURES TESTED

This section describes the performance measures used in evaluating both the effectiveness and drawbacks of the overall system for v6.04 and v6.0. The testing is performed to determine if the operational problems identified during the TTP are effectively addressed. Based on results of simulations, the following operational features were examined:

- Cockpit distractions during critical phases of flight

  Test the effectiveness of the raised RA-inhibit and aural alarm inhibit thresholds, as well as the reduced TA and RA alarm thresholds at low altitudes, by comparing the number of TAs and RAs issued on departure, on approach, and while transitioning in the terminal area.

- Unnecessary RAs on parallel approach and RAs that result in go-arounds

  Test the effectiveness of the reduced values for DMOD and TAUR thresholds for Sensitivity Level (SL) 3 below 2500 feet, and SL4 between 2500 and 5000 feet.

- The "Bump-up" phenomenon

  Test the effectiveness of the VTT logic by comparing the number and duration of positive, displacement-inducing RAs issued for a level TCAS against an intruder leveling off 1000 feet away.

- Displacements against legally separated VFR aircraft

  Test the effectiveness of the reduced ALIM values by comparing the number and duration of positive, displacement-inducing RAs issued against level threats approximately 500 feet away.

In assessing the effectiveness of the changed logic to address the characteristics noted above, both the encounters for which RAs were eliminated and those that remain were examined. In addition to assessing the overall effectiveness of the new logic in reducing the occurrence of undesirable and unnecessary RAs, separation at CPA, separation at the time of the RA, and displacement in response to RAs are relevant metrics. The following section presents the specific objectives of the T&E.

4.2 OBJECTIVES OF THE TEST AND EVALUATION

The objective of the T&E was to answer these specific questions based on the results of the simulations for v6.0 and v6.04:

QUESTION #1. What is the overall effectiveness of the new logic in reducing the number of RAs? This includes corrective RAs, crossings, reversals, increases, RAs that result in go-arounds, bump-ups, displacement against legally separated VFR traffic, and distraction during critical phases of flight.

QUESTION #2. When RAs were eliminated by 6.04, was there still adequate separation at CPA? If not, why not? When RAs were retained, was achieved separation adequate (i.e., was ALIM nominally achieved)?

QUESTION #3. With appropriate response to TCAS RAs, how much vertical displacement will we see with 6.04 as compared to 6.0? Has it been effectively reduced? In what cases do we still see large displacements?

QUESTION #4. How can we characterize the horizontal and vertical separation at the time of the RA for 6.04 as compared to 6.0? Is it clustered or scattered all over?

The following section describes the scenarios and data selected to help answer these questions. Section 5 provides answers to these questions based on simulations.

4.3 SCENARIOS USED FOR TESTING

Encounters derived from the recordings of the ARTS provided a good mix of IFR and VFR traffic, consisting primarily of low altitude encounters, with a wide range of geometries and closure speeds. Both the internal operation of the logic and the overall performance and practicality of the logic were assessed using ARTS encounters from the following locations:

- Dallas-Ft. Worth
- Denver
- Memphis
- Minneapolis-St. Paul
- Seattle
- LA Basin (LA, Burbank, Coast, and Ontario Terminal Radar Approach Control Facilities [TRACONs])
- New York
- St. Louis

These locations cover a wide range of densities and operations throughout the country. Hundreds of hours of data collected were used to generate the data base of encounters. Appendix C contains a brief description of the operations at each of these locations.

Encounters were derived from a spline fit of U.S. ARTS data to create second-by-second X, Y, and Z data for thousands of pairs of aircraft. Each pair was run through the CAS simulation with jittered inputs ten times with one aircraft equipped at a time—unless the ARTS data identified that aircraft as having a 1200-series Mode A beacon code, or unless it had an flight identifier starting with "N" followed by a digit. These latter were, for the purposes of this study, classed as non-TCAS aircraft. Every encounter was treated the same, so that the noise added to the inputs was the same noise for every first run, the same for every second run, the same for every third run, and so on. For this reason, it can be said that every first run is correlated, every second run is correlated, every third run is correlated, and so on. If an RA was generated for one or both aircraft equipped in at least four out of ten runs, that encounter was selected for inclusion in the database. Over 4000 RA encounters were selected from the ARTS data (see reference 2 for more details). These encounters were

then run through the v6.04 logic ten times to generate a set of results for comparison with v6.0. Table 1 provides the distributions used for statistical variations of inputs for ARTS encounters.

Results were collected based on the actual geometry data, the advisory sense, strength, and duration. In addition, displacement from the original path and achieved separation were calculated based on a timely, nominal response to RAs generated. The simulation models a five-second pilot delay (with jitter added), followed by obedient and timely response to RAs for the duration of the encounter. This also implies that all aircraft are capable of performing the simulated maneuvers (i.e., are not "performance limited" due to aircraft configuration.)

Section 5 provides more details on the results of the simulations, and a comparison of the performance for the two logics.

Table 1. Statistical Variations of ARTS Encounters

Input	Process	Type of Distribution	Mean	Sigma	Width	Quantization
Altitude	Randomly jittered	Gaussian	0	12 ft		1 ft for own 100 ft for intruder
Range	Randomly jittered	Uniform			62.5 ft	25 ft
RA Response Delay – Initial RA – Transitioning RA	Randomly selected	Uniform			 4-6 secs 1-3 secs	
RA Response Rate	Randomly jittered	Gaussian	ZDMODEL	300 fpm		
RA Response Acceleration – Nominal – Increase Rate/Reversal – Returning to original flight path	Randomly jittered	Gaussian	 .25 g .33 g .25 g	 .03125 g .0625 g .03125 g		

Note: Probability of reply = 1.0

SECTION 5

RESULTS

This section presents high level results comparing the two versions of the CAS logic. Simulations were run on more than 4000 ARTS derived encounters from eleven locations throughout the United States. In the simulation, each encounter involved a pair of aircraft tracks with one aircraft equipped with TCAS and the other unequipped, and was run ten times with randomly jittered position and pilot response inputs. The TCAS-equippage was then switched, and the pair of aircraft were run again to produce a new encounter. So every ARTS pair was run twice with each aircraft equipped separately, provided that the ARTS data did not show the aircraft as having a 1200-series Mode A beacon code, or a flight identifier starting with "N" followed by a digit. These latter were, for the purposes of this study, classed as non-TCAS aircraft, and, therefore, not simulated with TCAS-equippage. The questions posed in the previous section formed a basis for the comparison of the two logics. The following pages provide answers to those questions.

5.1 OVERALL EFFECTIVENESS OF VERSION 6.04

An evaluation of the two versions of the logic requires comparing the different characteristics that were discussed in section 4 and exploring the protection and ATC compatibility that is present after the change. The characteristics of the operational performance noted in the TTP are most easily seen by a multidimensional chart, as illustrated in figures 10a and 10b. While each site is different, results from Dallas-Ft. Worth (see figure 10a) are typical of the characteristics observed across all locations (see figure 10b). A description of operations for each location is contained in the appendix C. Included in these descriptions are runway configurations at primary airports, relative locations of nearby airports, and typical traffic patterns. These descriptions help to explain why some locations provided more or less of a particular type of encounter.

In these charts, the first pair of bars, labeled "All RAs", indicates the total number of encounters for which an RA was issued at least four out of ten times that encounter was run. If an RA is generated for each aircraft equipped, the pair of aircraft will be counted twice as two distinct encounters. The enclosed charts show that with the new logic there are fewer RAs issued (preventive and corrective). This varies from about 30 percent in Ontario (figure 10b) to about 75 percent in St. Louis. In addition, at Dallas-Ft. Worth, preventive RAs were issued one out of every four times (25 percent) for v6.0, but only one out of eight times (12 percent) for v6.04. At all locations, the percentage of preventive RAs went down for v6.04, showing that the RAs retained were more predominantly corrective and necessary.

Other bars in these charts give more details on the type of eliminated RAs. For instance, the next pair of bars, which addresses cockpit distractions at low altitude, compares the number

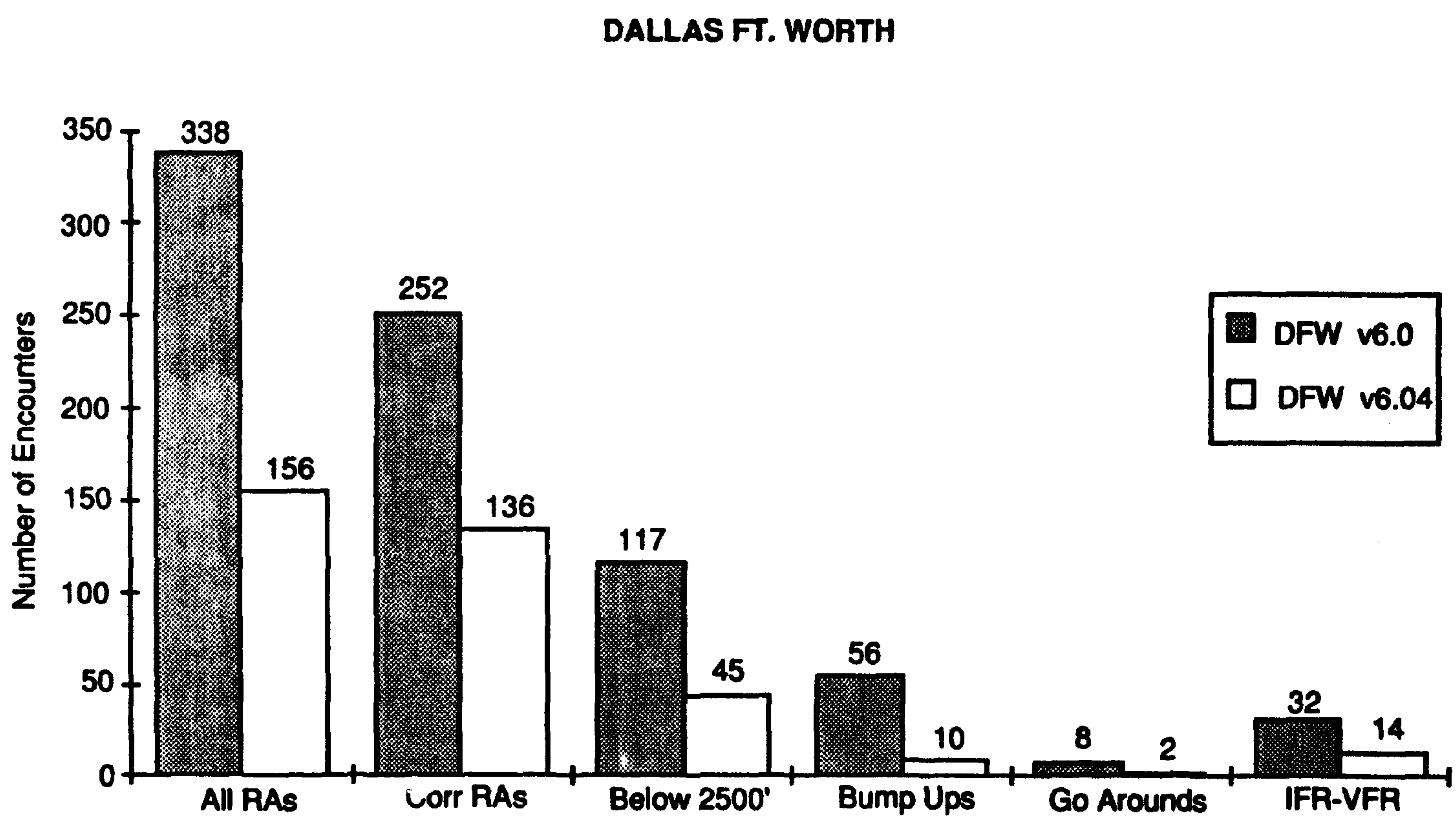


Figure 10a. Overall Benefits from v6.04 at Dallas-Ft. Worth

Reductions in all areas are visible here, in particular, RAs issued below 2500 feet AGL and "Bump-up" encounters. On a smaller scale, RAs resulting in go-arounds and displacements against legally separated VFR traffic were reduced as well. (Some encounters appear in more than one category.)

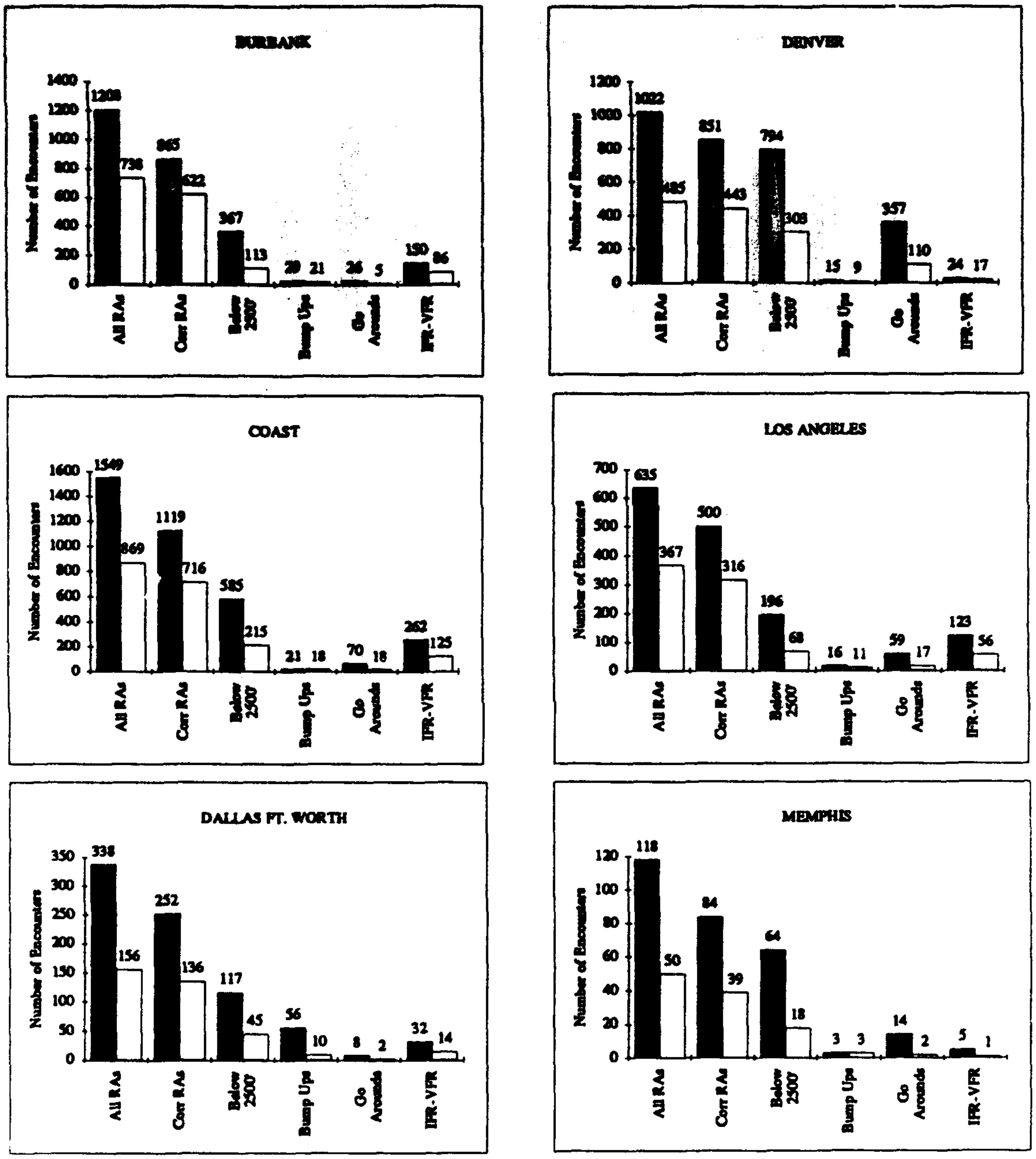


Figure 10b. Overall Benefits from v6.04 at All Locations

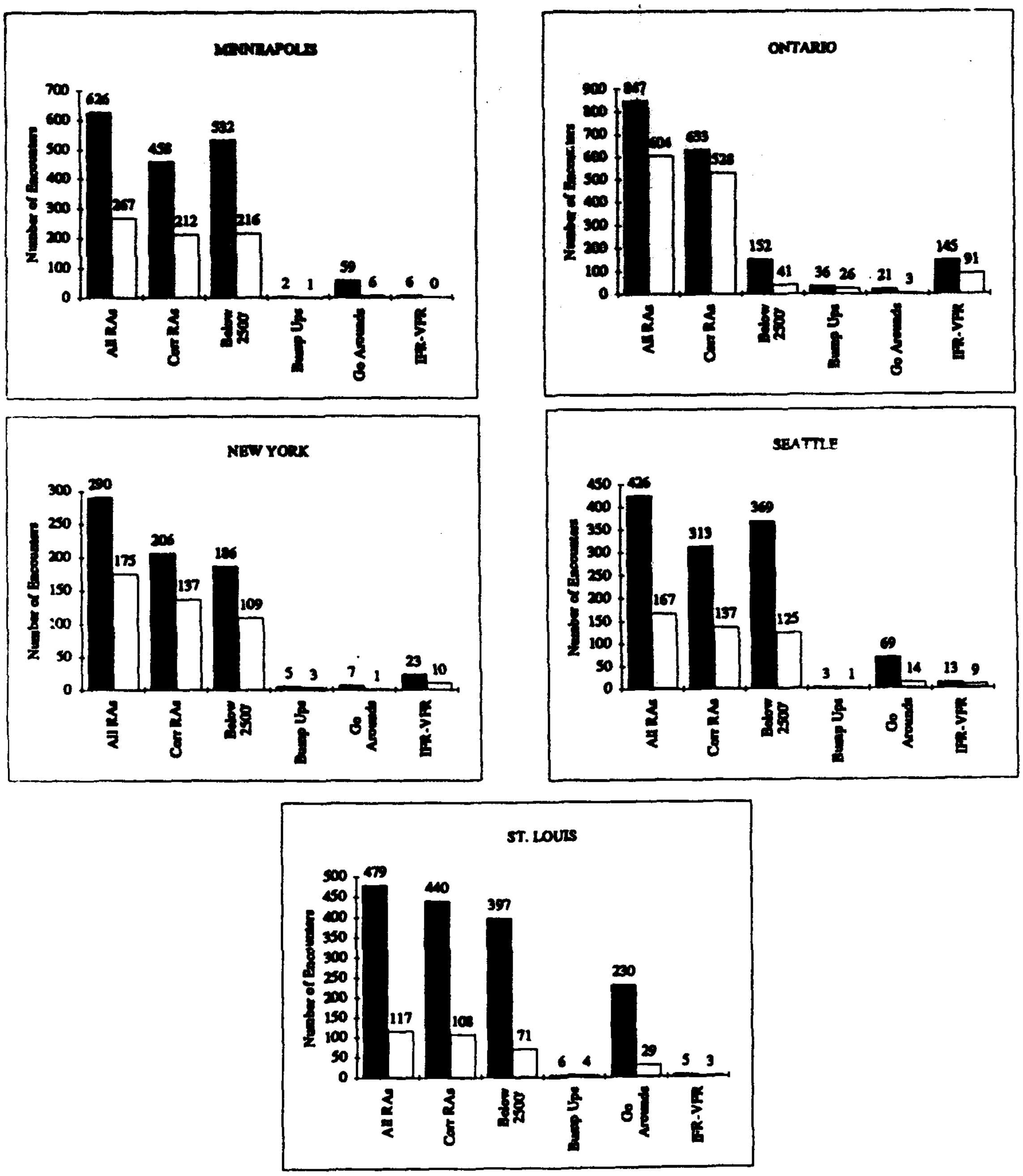


Figure 10b. Overall Benefits from v6.04 at All Locations (Concluded)

of RAs (preventive and corrective) that occurred below 2500 ft AGL. At most sites, these RAs constituted a substantial portion of the total. The improvement seen in figure 10a for Dallas-Ft. Worth is typical of that seen at most of the sites for v6.04; however, at New York the improvement was less striking.

The next pair of bars indicates the number of bump-up events. To review, the bump-up occurs when a TCAS-equipped aircraft is level, the intruder is climbing or descending toward it, intending to level off 1000 feet away. A positive, displacement-inducing "Climb" or "Descend" RA forces the TCAS-equipped aircraft several hundred feet away from its original altitude. The reduction in the number of bump-ups at Dallas-Ft. Worth is striking; although, at most other locations there was some improvement as well. A further discussion of displacements caused by response to RAs is contained in a subsequent section.

In an attempt to evaluate the effectiveness of the new logic in minimizing TCAS-induced go-arounds, results of the simulations were examined for corrective RAs in which both aircraft were below 3000 ft AGL and descending, and a "Climb" RA was issued. Encounters of this type were identified at Los Angeles, Memphis, Minneapolis, Seattle, and especially St. Louis (nearly half of the locations), and improvements were substantial at these locations. As shown by the corresponding pair of bars in figure 10a, encounters of this type did not appear to be present at Dallas-Ft. Worth.

Finally, to assess the interaction between legally separated IFR and VFR aircraft, the simulation results were examined for encounters involving two aircraft that were level and separated by approximately 500 feet (± 50 ft), and for which a positive, displacement-inducing "Climb" or "Descend" RA was issued. This type of encounter, like the bump-up, forces a level, TCAS-equipped aircraft away from its clearance. Encounters of this type were observed at Burbank, Coast, Dallas-Ft. Worth, Los Angeles, New York, and Ontario—about half of the sites. As exemplified in the last pair of bars in figure 10a, for Dallas-Ft. Worth, the new logic reduced this occurrence to about one-half of its previous value.

The following pages provide further statistics on the types of RAs eliminated by v6.04, and the effectiveness of the RAs that remain in achieving adequate separation.

The interoperability of TCAS systems v6.0 and v6.04 was also examined. No problems relating to possible incompatibility of the different logic versions were found. An interoperability analysis conducted by The MITRE Corporation is provided in appendix D. Further interoperability simulations using the various logic versions have been performed by the FAA Technical Center and are documented separately (reference 3).

5.2 SEPARATION AT CPA

As seen in the previous section, using the database of ARTS-derived tracks, with v6.04, there would be many fewer unnecessary RAs. It is important to characterize the encounters where

RAs are being eliminated and where they are being retained. Figure 11 shows the separation at CPA for the encounters occurring at Burbank where v6.04 eliminated the RA for either aircraft, and where the RA was retained. Each dot represents the separation, both vertically (VMD) and horizontally (HMD) at the CPA based on the smoothed ARTS-derived track (without TCAS). As the figure shows, the new logic eliminates many RAs (the open circles) with large miss distances. Figure 12 shows the distribution by altitude for all v6.0 RA encounters compared to v6.04 RA encounters at Burbank. A great many of the RAs that occur at low altitude are eliminated.

There are specific cases at many locations where separation is small but no v6.04 RA was issued. These cases of small separation (i.e., less than DMOD) are encounters involving aircraft on parallel approach which are not converging. There is a filter in the detection portion of the logic that disallows an RA in these cases (where the product of range and range rate is very small). For this reason, combined with the use of a smaller TAUR threshold in SL3 and SL4 and the raised RA inhibit threshold, a handful of "close encounters" will not result in an RA.

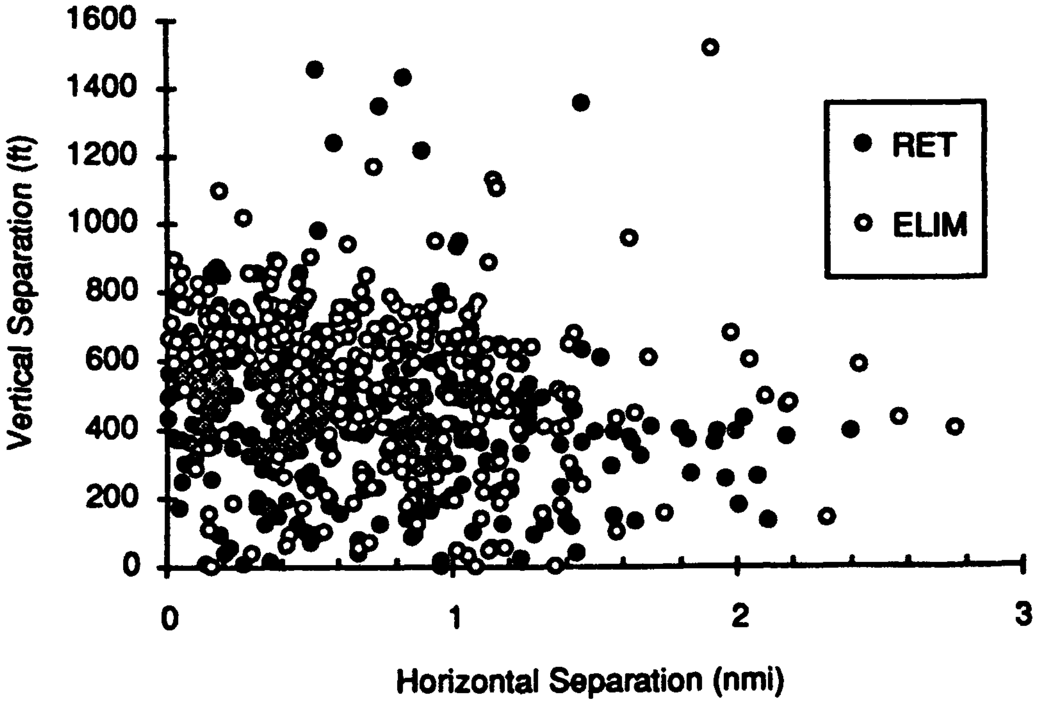


Figure 11. Separation at CPA for RAs Eliminated and Retained at Burbank

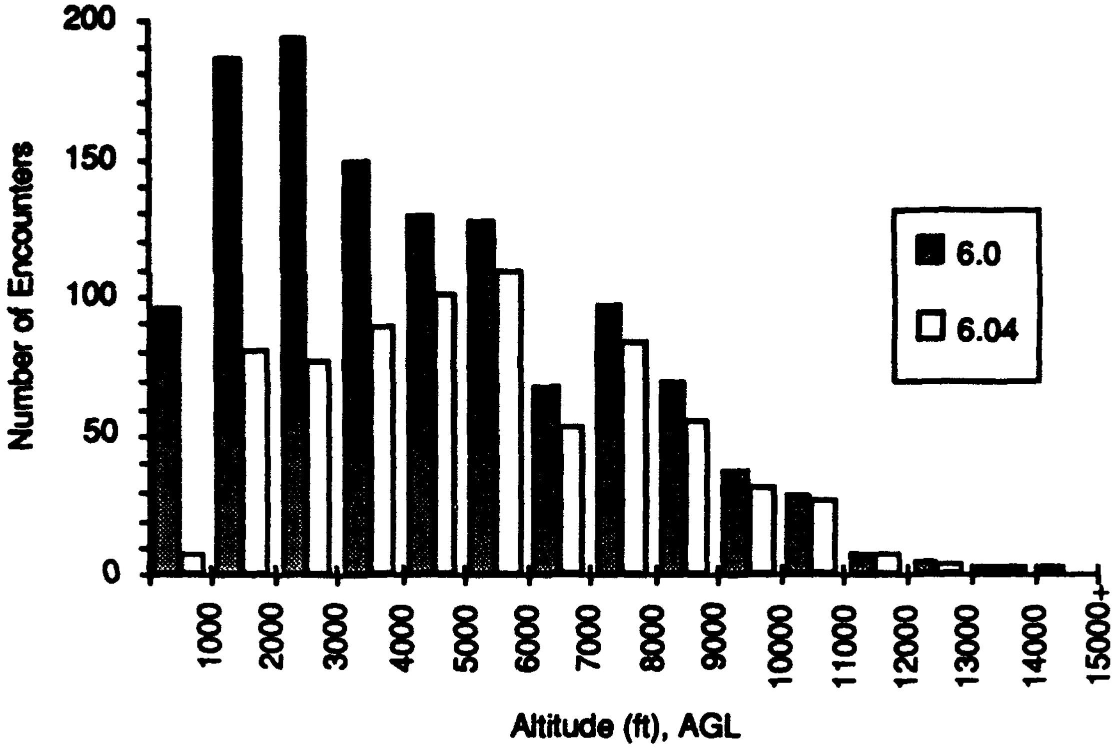


Figure 12. Distribution by Altitude for v6.0 Versus v6.04 RA Encounters at St. Louis

Finally, it is essential to assess the separation achieved by v6.04 RAs. Figures 13a and 13b show this information for Burbank. For each encounter resulting in an RA, the original, ARTS-derived VMD and HMD are plotted (figure 13a), along with the appropriate response to the RA issued (figure 13b). In some cases, achieved separation was commendable (separation increased). In other cases, RAs issued against intruders separated horizontally by more than a mile or diverging resulted in less achieved separation. Adequate separation was achieved either vertically (200 ft) or horizontally (.2 nmi), in every case but two. In both cases, RAs were issued but inhibited a few seconds later as the aircraft descended into the RA-inhibit regime. There were similar cases found at other locations where aircraft became increase descend-inhibited or descend-inhibited during the encounter. Each encounter was investigated for proper logic operation, and verified as such. No such cases of reduced separation were identified.

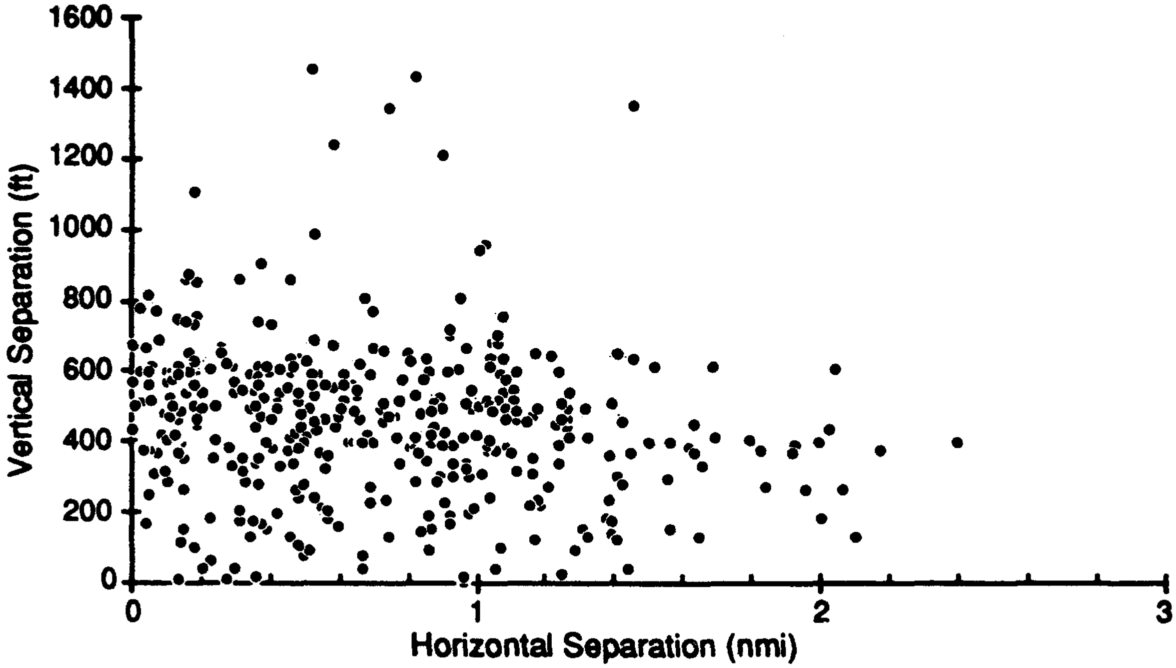


Figure 13a. Original Separation for v6.04 RAs at Burbank

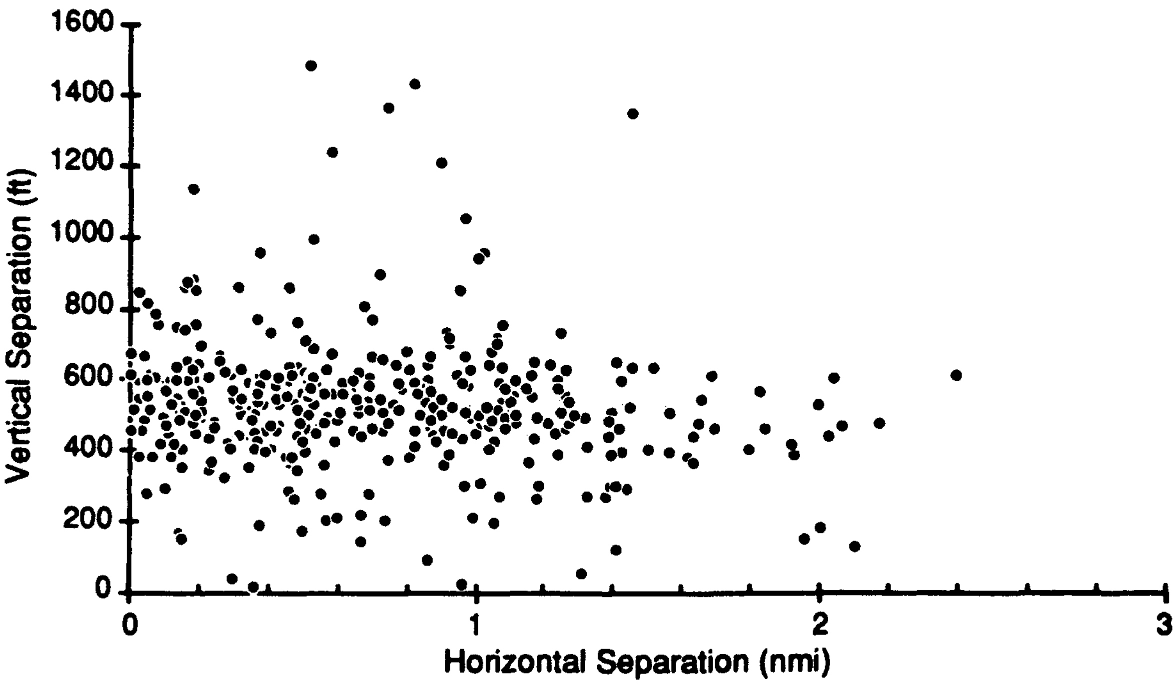


Figure 13b. Achieved Separation for v6.04 RAs at Burbank

5.3 VERTICAL DISPLACEMENTS

Due to a reduction in ALIM values and RAs being issued later in the encounter, positive, displacement-inducing RAs should be both less prevalent and smaller in magnitude for v6.04 than for v6.0. Vertical displacement is defined as the maximum (across all ten runs of the encounter) number of feet from a level flight path, achieved in response to an RA. Displacement from level flight was isolated for the purposes of studying the propensity of TCAS for bumping pilots off their altitudes when above 2500 feet AGL. Figure 14, shown below, provides the distribution of displacements experienced for v6.0 versus v6.04 RAs at Memphis. Some locations revealed a few high displacements from the original flight path (i.e., greater than 1000 feet) with the v6.0 logic, as shown below in figure 15 for Denver. These were eliminated by v6.04; however, due to slow closure speeds in certain encounters (typically parallel approach), some long positive RAs remained resulting in displacements of more than 600 ft. Displacements at Dallas-Ft. Worth were substantially reduced (see figure 16), as they were throughout the database.

5.4 SEPARATION AT TIME OF CORRECTIVE RAs

Some aspects of the interaction between ATC and TCAS can be characterized by examining the separation between the two aircraft at the approximate time corrective RAs were issued. Figure 17 provides an example of the vertical and horizontal separation at the approximate time corrective RAs were issued for Burbank. Most v6.04 corrective RAs are issued where the two aircraft are less than 1000 feet away vertically and less than three miles horizontally, or five miles at higher altitudes. Figure 18 shows the same information for Dallas-Ft. Worth.

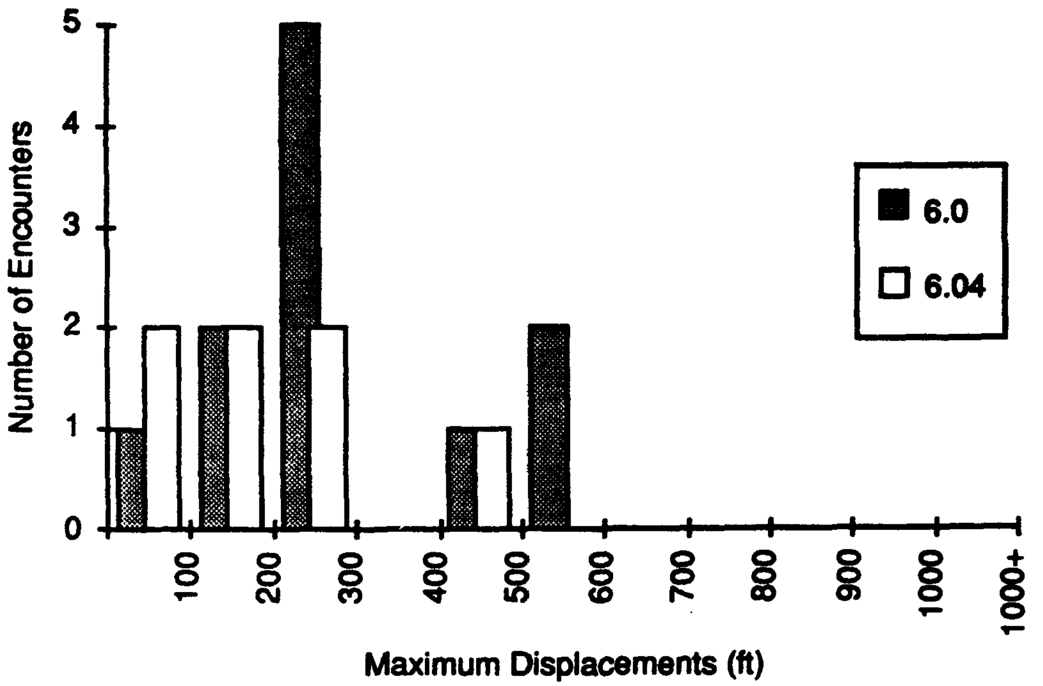


Figure 14. Vertical Displacement From v6.0 Versus v6.04 RAs at Memphis

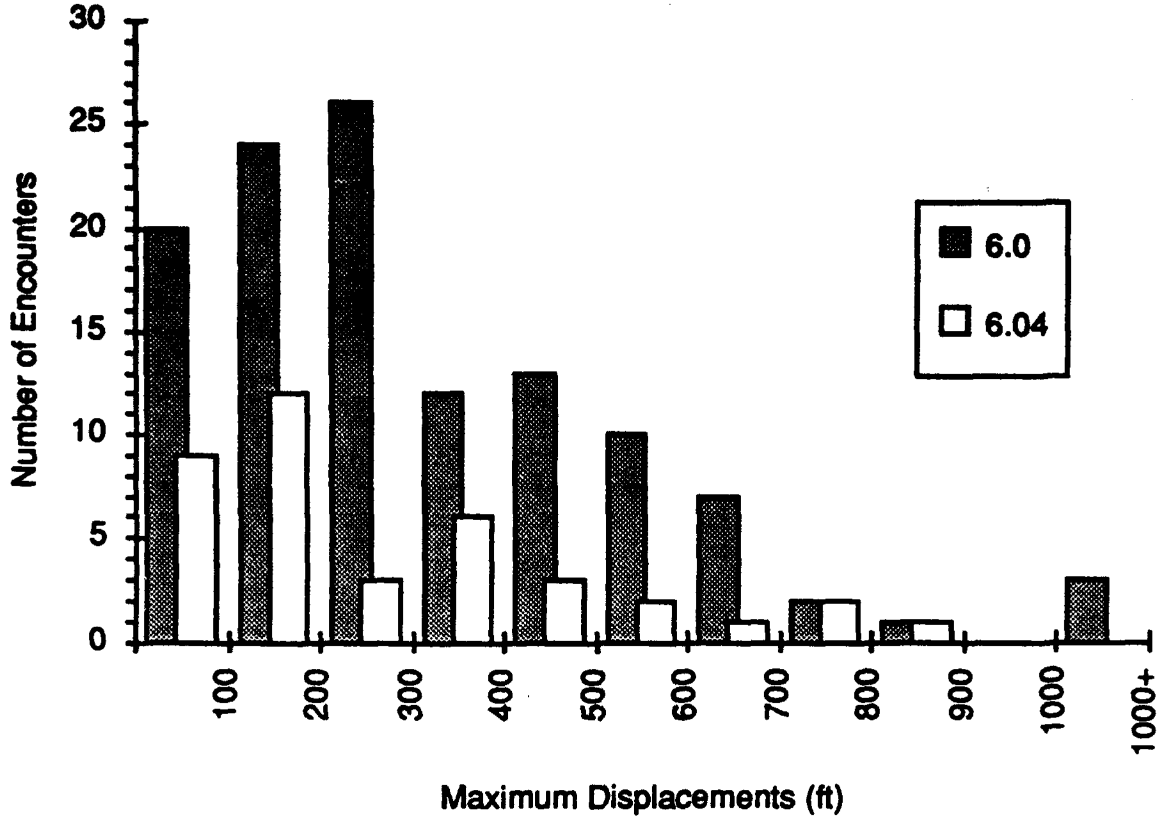


Figure 15. Vertical Displacements From v6.0 Versus v6.04 at Denver

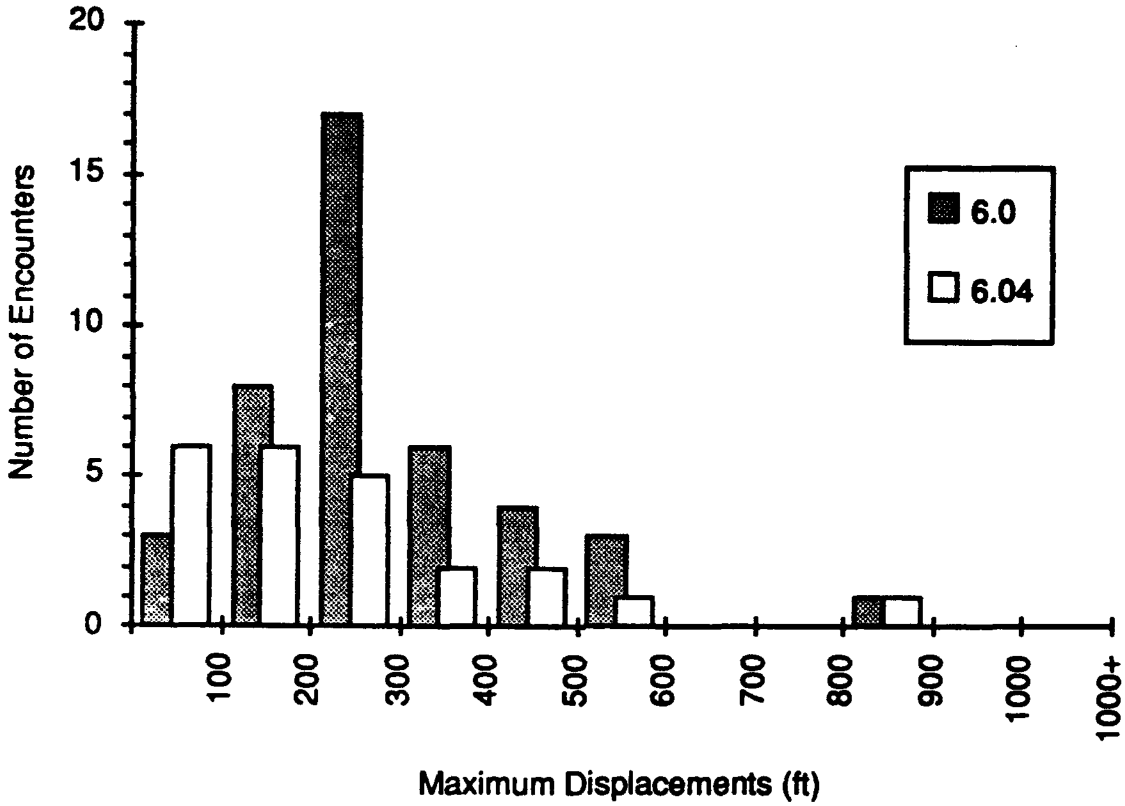


Figure 16. Vertical Displacements From v6.0 Versus v6.04 at Dallas-Ft. Worth

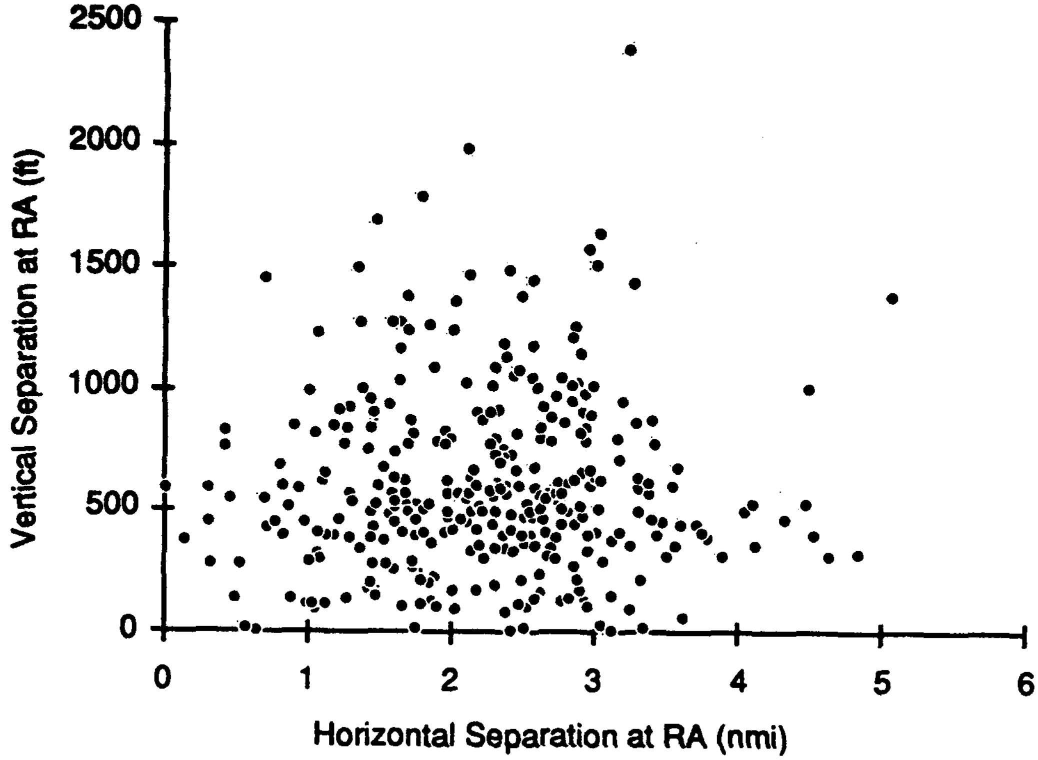


Figure 17. Separation at Approximate Time of Corrective RAs at Burbank

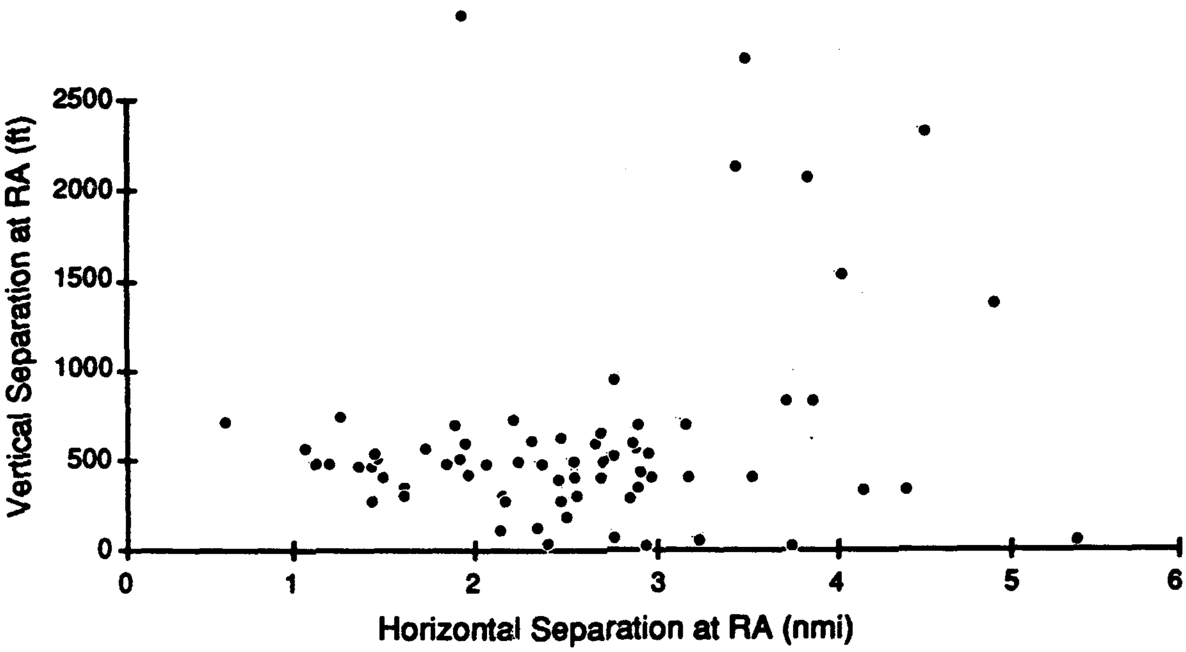


Figure 18. Separation at Approximate Time of Corrective RAs at Dallas-Ft. Worth

SECTION 6

CONCLUSIONS

The TCAS II v6.04 logic appears to be operating properly with no adverse effects on any unaltered portions of the logic. No errors have been found in the modifications introduced by v6.04. Any errors found in the unaltered portions of the logic have been documented and addressed through PTRs. Resolution of these will occur as part of subsequent logic change packages.

Operationally, results of simulations show that the new logic features in v6.04 appear to be very effective in reducing unwanted alerts, thus creating a more compatible ATC-TCAS environment. Specifically, TAs and RAs in critical phases of flight were reduced. RAs issued at low altitude and on parallel approach were reduced dramatically. The "bump-up" phenomenon was substantially reduced. Unnecessary displacements against legally separated VFR traffic were reduced as well. These four enhancements will contribute to a more acceptable version of TCAS II.

The testing provided an extensive understanding of the operation of TCAS v6.04 in all airspace. The end product of the T&E was a version of the CAS logic that still provided effective separation, while having a significant reduction in the frequency of unnecessary alarms. To recap the specific advantages of the v6.04 logic, the following points can be made from the simulation results of ARTS-derived encounters:

- With the new logic there are fewer RAs (preventive and corrective). The overall reduction in the number of RAs issued varies from 30 percent in Ontario to about 75 percent in St. Louis.
- At all locations, the percentage of preventive RAs went down for v6.04, showing that the RAs retained were predominantly corrective and necessary.
- RAs issued below 2500 feet AGL at most sites constituted a substantial portion of the total. Reductions were seen at most of the sites; however, at New York the improvement was less noticeable.
- The reduction in the number of "bump-ups" at Dallas-Ft. Worth is striking, and at most other locations there was some improvement as well.
- Go arounds on approach due to v6.0 RAs were identified at nearly half of the locations, and improvements were substantial at these locations for v6.04.
- The new logic reduced the occurrence of displacements against legally separated VFR traffic by about 50 percent.

- For all locations, separation at CPA for encounters no longer resulting in an RA with v6.04 appears to be adequate.
- Large vertical displacements experienced due to RA responses will be substantially less for v6.04 than for v6.0.
- Most v6.04 RAs are issued when the two aircraft are within nominal IFR ATC separation standards (i.e., less than 1000 feet away vertically and less than three miles horizontally, or five miles at higher altitudes).

The enhancements contained in v6.04 of the TCAS II logic contribute to making TCAS considerably more compatible with the ATC environment, provide a TCAS logic that is about half as intrusive as v6.0, and result in a substantial improvement in the quality of the system.

LIST OF REFERENCES

1. Zeitlin, Dr. Andrew D., Dr. Michael P. McLaughlin, July 1992, *Safety Study of TCAS II for Logic Version 6.04*, MTR 92W0000102, The MITRE Corporation, McLean, VA.

2. Owen, U. and D. Tharp, (to be published), *The Creation of an Encounter Database of TCAS Events from ARTS Recordings*, WP 92W0000224, The MITRE Corporation, McLean VA.

3. Choyce, T., K. Ciaramella, and P. Kelly, July 1992, *Test and Evaluation of TCAS II Logic Version 6.04*, DOT/FAA/CT-ACD32092/4, FAA Technical Center, Atlantic City International Airport, NJ.

APPENDIX A

CONTENTS AND JUSTIFICATION OF VERSION 6.04

JUSTIFICATION AND RATIONALE FOR VERSION 6.04 OF THE TCAS II LOGIC

David J. Lubkowski
The MITRE Corporation

23 June 1992

SECTION 1

INTRODUCTION

Since the release of version 6.0 (v6.0) of the Traffic Alert and Collision Avoidance System II (TCAS II) Minimum Operational Performance Standards (MOPS), requests for changes to the TCAS II logic have been made in order to correct errors, enhance its performance, and make TCAS more compatible with the Air Traffic Control (ATC) system. The requests have been generated by the TCAS manufacturers, airlines, pilots, controllers, airframe manufacturers, The MITRE Corporation, MIT Lincoln Laboratory, ARINC Research, and the Federal Aviation Administration (FAA), and were submitted to The MITRE Corporation either as Problem/Trouble Reports (PTRs) or as Change Request Forms (CRFs). These requests have been reviewed and prioritized by the Radio and Technical Commission for Aeronautics (RTCA) Special Committee 147 (SC-147) Requirements Working Group (RWG), with development and testing of the most urgent changes being performed at The MITRE Corporation and the FAA Technical Center.

To date, two groups of changes have been developed, tested, and released to the TCAS manufacturers, primarily correcting the performance of the logic that models response to "Climb" or "Descend" Resolution Advisories (RAs) when own aircraft is climb- or descend-inhibited, respectively.

Another group of changes, some correcting minor display-related errors and others addressing concerns about TCAS' interaction with the ATC system, has also been developed and tested, together with those that were previously released. In order to ensure completeness and ease of configuration control, a decision was made to combine all of the changes that were developed subsequent to the release of v6.0 into a single change package called version 6.04 (v6.04). As part of that package, the existing bench tests specified in the TCAS MOPS were modified and new bench tests, designed to specifically exercise the v6.04 changes, were added so that the manufacturers can demonstrate correct implementation within their systems.

Pseudocode change pages for v6.04 were supplied to the TCAS manufacturers at the RTCA SC-147 meeting in April 1992. The bench tests are being provided separately prior to the next meeting of SC-147 in August 1992. In addition, the entire set of pseudocode changes and the revised bench tests were provided to the FAA Technical Center for independent evaluation in their simulation facility.

This document presents the justification and rationale for the logic and parameter changes contained in v6.04. The changes are grouped as follows:

- Editorial corrections
- Modeling when own aircraft is climb- or descend-inhibited

- Sense reversal Resolution Advisories (RAs)
- Increase Rate RAs
- Sense selection when own aircraft is climb-inhibited
- Nuisance Alarm Filter (NAF)
- Mode S-equipped threats: handling loss of altitude and dropped tracks
- RA Display logic
  - Corrective/preventive determination
  - Selection of goal rate for Increase Rate RAs
  - Vertical rate to display
- RA inhibit altitude and aural inhibit altitude
- Reasonableness checks for own aircraft fine altitude and radar altitude
- Traffic Advisory (TA) threshold reductions
- Sensitivity level selection
- RA altitude threshold reductions
- Vertical Threshold Test (VTT)

In the sections that follow, the PTRs and CRFs associated with each of the change groups are listed, and the intended functional requirement for the CAS logic, if one exists, is stated, along with the justification for making the change. The design elements of each change are also described and the rationale for that design and any parameters that it uses is provided where necessary.

SECTION 2

VERSION 6.04 MODIFICATIONS TO THE TCAS LOGIC AND PARAMETERS

Each of the changes included in v6.04 is listed in table 1. Each is classified as to whether it is a logic correction, parameter change, or logic change; and the problem that it addresses is described. Those changes associated with PTRs are listed first, followed by those associated with CRFs.

The majority of these changes either involve simple parameter value modifications or the addition or modification of one or two lines of pseudocode. The changes are distinct from one another and are easily tested using specific encounter geometries. The logic changes, for the most part, support the selection of the new or revised threshold parameters and are extensions of threshold selection logic that already exists.

2.1 EDITORIAL CORRECTIONS

PTR 15 and CRF 6 pertain.

Two editorial corrections to the high-level pseudocode have been made. The solution to PTR 15 corrects an error in **PROCESS** Corrective_preventive_test, in which the high-level code incorrectly refers to own aircraft "climbing" rather than "descending" in the clause that sets the corrective climb flag when both RA response goal rates are 0 fpm. The solution to CRF 6 ensures that the phrase used in **PROCESS** Altitude_separation_test to describe sense selection when own aircraft is climb-inhibited is consistent with those used elsewhere in the logic. The changes addressed by PTR 15 and CRF 6 were necessary to eliminate ambiguity within the high-level description of the logic, even though the low-level pseudocode was correct.

2.2 MODELING WHEN OWN AIRCRAFT IS CLIMB- OR DESCEND-INHIBITED

2.2.1 Statement of Requirement

When own aircraft is climb- or descend-inhibited, or is involved in a multi-aircraft encounter where a pre-existing RA precludes modeling a positive RA of the opposite sense, the TCAS logic shall not model response at 1500 fpm for the inhibited direction, but must use 0 fpm. The logic shall model acceleration to 0 fpm if own aircraft is not in level flight. This not only applies when own aircraft is climb-inhibited and descending, but also if own aircraft is climb-inhibited and climbing. The same is true for modeling when descend-inhibited. Furthermore, when own aircraft is above the descend-inhibit threshold (1100 ft AGL +/- 100 ft), response to a Descend RA shall not be modeled below P.ZDESBOT (900 ft AGL).

Table 1. Contents of Version 6.04

PTR No.	Classification	Descriptio Problem/Impact of Solution
10	Logic Correction	Incorrect modeling of TCAS response to a descend sense RA when TCAS is descend-inhibited (When TCAS is below 900 ft AGL, the logic models TCAS achieving 900 ft in response to a descend sense RA). (5 lines of pseudocode: 3 added; 2 modified)
11	Logic Correction	TCAS only permits sense reversals of positive Climb or Descend RAs, when it should permit sense reversal for any RA strength. (1 line of pseudocode modified)
12	Logic Correction	Incorrect calculation of acceleration to achieve RA goal rate when that rate is 0 fpm. (2 lines of pseudocode: 1 added; 1 modified)
13	Logic Correction	Logic incorrectly biases toward selection of altitude crossing climb sense when own is climb-inhibited and threat is above, but projected to pass below. (1 line of pseudocode modified in each of three subroutines)
14	Logic Correction	Simultaneous setting of "Corrective Climb" and "Corrective Descend" flags could occur in multi-aircraft situations where a single positive RA is converted to a dual negative RA ("Don't Climb and Don't Descend"). (4 lines of pseudocode added)
15	Editorial Correction	High-level description for PROCESS Corrective_ preventive_test incorrectly refers to own aircraft "climbing" rather than "descending". (No changes to low-level logic pseudocode)
16	Logic Correction	Incorrect modeling when own aircraft is climb- or descend-inhibited and is climbing or descending, respectively. Logic models continuation of current vertical rate rather than level-off. Could result in a "Don't Descend" RA when own is still below the threat, or a "Don't Climb" RA when own is still above the threat. (6 lines of pseudocode added)

PTR No.	Classification	Description of Problem/Impact of Solution
17	Logic Correction	Incorrect setting of "altitude-crossing" flag when own aircraft is climb- or descend-inhibited. This problem is corrected by the logic changes associated with PTRs 12 and 16. (No change to pseudocode)
18	Logic Correction	The modeling logic used when TCAS has low confidence in a threat's vertical rate needs to account for the case when own aircraft is descend-inhibited. It already does so when own aircraft is climb-inhibited. (1 line of pseudocode modified)
21	Logic Correction	Goal Rate for an Increase Rate RA issued during a multi-aircraft situation could revert to nominal RA rate, depending on order of threats in the Threat File. (2 lines of pseudocode modified)
28	Logic Correction	The inequality used in PROCESS Cross_through_check to determine if the threat has crossed own aircraft's altitude needs to be identical with that used in PROCESS Crossing_flag_check. Otherwise, the RA sense reversal could be delayed one cycle. (1 line of pseudocode modified)
30	Parameter Change	When own aircraft has a vertical rate exceeding 10,000 fpm, the corrective RA flag is set even though no RA is displayed. (Parameter value changed (increased))
31	Editorial Correction	Rate to display for all types of positive RAs (Climb, Descend, Maintain Climb, Maintain Descent, Increase Climb, Increase Descent) needs to be sent to RA display, not just those for Maintain Climb and Maintain Descend. (1 line of pseudocode comment modified)
32	Logic Correction	Logic can require maintenance of vertical rate in excess of 2500 fpm (goal rate for Increase Rate RA) if the pilot exceeds 2500 fpm in responding to the Increase Rate RA. It should not require maintenance of any rate exceeding 2500 fpm in response to such an RA. (6 lines of pseudocode: 4 added; 2 modified)

PTR No.	Classification	Description of Problem/Impact of Solution
34	Logic Correction Parameter Change	Nuisance Alarm Filter (NAF) delays RAs against aircraft that approach within DMOD nmi of own aircraft and are within the TCAS altitude threshold. An RA is required in such instances. In addition, the NAF range threshold needs to be expanded for use in SL7 in order to meet the requirement to issue an RA when a threat comes within DMOD. (1 line of pseudocode modified and 1 parameter value changed (increased))
35	Logic Correction	Unnecessary setting of sense reversal flag in multi-aircraft encounters. (1 line of pseudocode modified)
36	Logic Correction	Increase Rate RAs should not be issued in altitude-crossing encounters if the threat is projected below own aircraft's current altitude when a Descend RA is displayed, or is projected above own aircraft's current altitude when a Climb RA is displayed. (2 lines of pseudocode modified)
40	Logic Correction	Run-time error can occur if a Mode S equipped threat stops reporting altitude while TCAS is displaying an RA against it, and then subsequently reports altitude again. Threat status must be cleared when the threat's altitude is lost. TF entry must also be deleted so logic will not use old data if alt. is again reported. (2 lines of pseudocode: 1 added; 1 modified)
43	Parameter Changes Logic Changes	Incorporation of the Vertical Threshold Test to handle the "bump up" encounter class (tables 4-2 and 5-1 modified with parameter value changes for ZTHR and new vertical TAU thresholds added for this encounter class; STRUCTURE P modified; 8 lines of pseudocode changed to support vertical threshold selection: 5 added; 3 modified)
46	Logic Change	Comments added to require reasonableness checks on radio altimeter input values (Logic to be developed by each TCAS manufacturer)
49	Logic Change	Comments added to require reasonableness checks on own fine altitude input values (Logic to be developed by each TCAS manufacturer)

CRF No.	Classification	Description of Problem/Impact of Solution
6	Editorial Correction	Consistency in phrases used in high-level description of PROCESS Altitude_separation_test. (No changes to logic pseudocode)
14	Logic Correction	Do not use hysteresis in determining if an initial RA is corrective or preventive. Only use hysteresis when an RA is transitioning from preventive to corrective. (12 lines of pseudocode: 4 added; 8 modified)
15	Parameter Changes Logic Changes	Reduce TA altitude thresholds to eliminate TAs against legally separated IFR aircraft. (Incorporation of new TA thresholds into table 4-2 indexed by altitude layer; STRUCTURES G and P modified, two lines of pseudocode changed to support TA alt. threshold selection: 1 added; 1 modified.)
19	Parameter Changes	Reduce positive RA altitude threshold (ALIM) values to reduce the number of unnecessary displacement-inducing RAs, especially in IFR/VFR encounters. (Parameter values changed for ALIM in table 4-2)
34	Logic Change	The current logic design prevents reversing the sense of an altitude-crossing RA that has strengthened to an Increase Rate RA, even if the threat is leveling off. Sense reversals based on encounter geometry should be permitted irrespective of the type of RA issued. (6 lines of pseudocode: 4 added; 2 modified.)
35	Logic Correction	The equations that project the intruder aircraft's altitude at closest approach, and which are used in PROCESS Reversal_check and PROCESS Crossing_flag_check, should cap that projection n the way that is done in the RA modeling logic. Doing so will result in earlier detection of a level-off maneuver, resulting in earlier sense reversal. (1 line of pseudocode modified in each of two routines)
46	Parameter Change	To reduce the number of TAs at low altitude, the TA TAU thresholds should be reduced. RTCA PWG suggests reducing threshold by five seconds for SL3 and SL4. (TA TAU values changed in table 7-1)

CRF No.	Classification	Description of Problem/Impact of Solution
48	Parameter Change	Many RAs at low altitude are unnecessary and can result in go-arounds that are disruptive to ATC operations. The RA-inhibit altitude should be raised. PWG suggests raising it to some value between 800 and 1100 ft. (1000 ft +/- 100 ft hysteresis) (two parameter value changes (upper & lower hysteresis bounds))
49	Logic Change Parameter Changes	Many RAs issued on parallel approach are unnecessary. Sensitivity level 3 should be used. (SL3 inserted in altitude band where SL4 was used. SL4 moved up to replace part of former SL5 regime.) (STRUCTURE P and table 7-1 modified; Parameters for switching thresholds for SL2, SL3, SL4, and SL5 modified; two parameters for SL initialization deleted; CRFs 49, 87 and 88 all modify the same set of pseudocode. 53 lines modified & added in all.)
73	Parameter Change	TCAS is issuing TAs against aircraft that are either on the ground or close to the ground. (Altitude allowance for declaring intruder on ground has been raised.) (two parameter value changes (upper & lower hysteresis bounds)
75	Parameter Change	The aural inhibit for TAs should be raised to reduce cockpit distraction at low altitude. (Threshold raised to correspond to RA-inhibit threshold.) (two parameter value changes (upper & lower hysteresis bounds))
87	Logic Change	The current sensitivity level selection logic does not permit desensitization from SL6 to SL5 based on radar altitude. This means that at certain high-altitude airports, TCAS would remain at full sensitivity until the aircraft landed and could result in unnecessary TAs and RAs. (Logic modified to take radar altitude into account in SL6 and SL7.) (CRFs 49, 87 and 88 all modify the same set of pseudo-code. 53 lines total modified & added.)

CRF No.	Classification	Description of Problem/Impact of Solution
88	Logic Change	The current sensitivity level selection logic does not permit transitions from any SL to any other SL to occur within a single cycle. No requirement exists. (STRUCTURE P modified; logic modified to enable upward transitions to occur within one cycle, and downward transitions to step one SL per cycle. The ability to transition upward within one cycle enables TCAS to come up after a restart at the proper SL.) (CRFs 49, 87 and 88 all modify the same set of pseudocode. 53 lines total modified & added.)
106	Logic Change Parameter Change	The Traffic Advisory Immediate Range Test uses threshold values that are larger than the minimum range threshold required for TAs (DMODTA). Its order of use within the logic, prevents operation of subsequent logic that uses DMODTA. Use of this test and its thresholds can result in many unnecessary TAs, especially at low altitudes. (The test and its thresholds have been deleted.) (STRUCTUREs P, TRAFVAR and table 7-1 modified; table entry for Immediate Range Test thresholds has been deleted, along with local variable for the threshold selected. Two lines of pseudocode have been deleted; one line modified.)
126	Logic Change Parameter Change	To enable reductions in the TCAS TA and RA alert rates, add more altitude layers and reduce the thresholds contained therein. Provide for increased threshold selection flexibility at lower altitudes. (STRUCTUREs G, P and table 4-2 modified; Number of altitude layers below FL100 increased; existing logic extended to handle the additional layers and thresholds; entry for variable TA alt. threshold added to tables; switching thresholds for new alt. layers defined) (11 lines of pseudocode added)

These requirements apply whether high- or low-confidence in the threat's vertical rate exists at the time of RA sense selection.

2.2.2 Changes to the Modeling Logic When Own Aircraft is Climb- or Descend-Inhibited

PTRs 10, 12, 16, 17 and 18 pertain.

In the v6.0 logic, the modeled response to a Descend RA when own aircraft was not descend-inhibited was calculated correctly (i.e., own aircraft was modeled as descending at 1500 fpm to achieve an altitude no lower than 900 ft AGL); however, if own was descend-inhibited at the time modeling took place, the logic still modeled a full 1500 fpm response to a Descend RA even though such an RA could not be issued. That modeled response was then capped to be no lower than 900 ft AGL, even if own was already below 900 ft AGL. This problem was inherent in the TCAS logic prior to v6.0, but was exposed when the descend-inhibit threshold was raised from 700 ft AGL to 1100 ft AGL because the altitude band of susceptibility was larger. The solution to PTR 10 addressed this by: (1) modifying PROCESS Modeling_calculations to model 0 fpm when own aircraft is descend-inhibited, and (2) restricting the application of the 900 ft AGL minimum descent altitude to situations where own aircraft was not descend-inhibited (ROUTINE Separation_over_interval).

PTR 12 addressed an error in the RA response modeling logic, which prevented calculation of the time spent at the current (initial) vertical rate, time to accelerate, vertical goal rate achieved and time spent at that goal rate, for cases where own aircraft was climb- or descend-inhibited. The error involved the use of the goal rate variable for a dual purpose: specifying the desired goal rate for a given RA, and serving as the discriminant to determine if the quantities listed above needed to be calculated. The fact that a value of 0 fpm was used for both purposes meant that the quantities listed above were never calculated whenever own aircraft was climb- or descend-inhibited. The solution to PTR 12 uses a different variable as the discriminant. That variable is explicitly set whenever an acceleration to a particular goal rate is needed, irrespective of the value of the selected goal rate (ROUTINE PROJECT_VERTICAL_GIVEN_BITS).

PTR 16 addressed the fact that the v6.0 logic did not model a response rate of 0 fpm if own aircraft was climb-inhibited and climbing or descend-inhibited and descending. That logic instead modeled own aircraft continuing its vertical rate, and based its sense selection on the predicted separation, even though it could not issue an RA to maintain that rate. A subsequent level-off by own aircraft, which was a response permitted by the displayed preventive RA, could result in much less separation than would have occurred had an RA of the opposite sense been chosen initially. This was especially true if the preventive Don't Descend or Don't Climb RA was issued while own aircraft was still below or above the threat aircraft, respectively, in essence being an altitude-crossing RA. The solution to PTR 16 addressed this by having the logic calculate a reduction of vertical rate to 0 fpm when own

aircraft has a rate in the inhibited direction. The changes affected ROUTINE PROJECT_VERTICAL_GIVEN_BITS.

Solving the two problems identified by PTRs 12 and 16 also resolved another problem described in PTR 17, that is, the incorrect setting of the ITF.INT_CROSS flag in cases where:

- Own is climb- or descend-inhibited and climbing or descending, respectively;
- The selected RA is Don't Descend (climb-inhibited case) or Don't Climb (descend-inhibited case); and
- Own aircraft is more than 100 ft below the threat (climb-inhibited case) or more than 100 ft above the threat (descend-inhibited case).

Because the geometry in these cases is altitude-crossing and the logic design assumes that the crossing could not be caused by the negative (Don't Climb or Don't Descend) RA, the intruder aircraft is assumed to be responsible for the crossing and the ITF.INT_CROSS flag is set. This could result in a sense reversal a few seconds later, depending on the encounter geometry. Because the solutions to PTRs 12 and 16 corrected the modeling logic calculations associated with the conditions listed above, the occurrence of an altitude-crossing Don't Climb or Don't Descend RA is no longer possible and there is no need to modify the logic where the crossing flag is set (PROCESS Crossing_flag_check).

Finally, the requirement that the modeling logic also account for climb- or descend-inhibits even under conditions of low confidence in the threat's vertical rate, was addressed by the solution to PTR 18. The v6.0 logic already contained pseudocode to handle the low confidence climb-inhibited case, but lacked equivalent code for the descend-inhibited case. The code in PROCESS Model_worst_rate_errors was modified to do this by testing for the descend-inhibit condition and substituting the appropriate value, 0 fpm, as the goal rate to model.

2.3 SENSE REVERSAL RAs

2.3.1 Statement of Requirements

The TCAS logic shall be capable of reversing an RA of any strength.

The TCAS logic shall not reverse the sense of an altitude-crossing RA that requires maintenance of own's vertical rate (ITF.OWN_CROSS is set) when TCAS is involved in a multi-aircraft encounter. (Note: Maintenance of own's vertical rate may be necessary to avoid two or more threats that are so close to one another vertically that they preclude conversion of the positive RA to a dual negative.)

Projections of the threat aircraft's altitude at the point of closest approach, which are used by the sense reversal and crossing flag logic, shall be made using true TAU clipped to a maximum value in the same way done by the maneuver modeling logic.

The definition of an altitude-crossing RA shall be an RA whose sense requires crossing through the altitude of the threat, irrespective of which aircraft is responsible for the crossing geometry and when the RA was issued, own aircraft was separated from the threat by at least 100 ft vertically.

2.3.2 Changes to the Sense Reversal Logic

PTRs 11, 28 and 35, and CRFs 34 and 35 pertain.

The first requirement stated above has two implications for the v6.0 logic. The first is that PROCESS Cross_through_check, which reverses the sense of a noncrossing RA if the

geometry becomes crossing, contains an error in the low-level pseudocode that only permits sense reversals of positive Climb or Descend RAs. The high-level pseudocode, on the other hand, is correct. The solution to PTR 11 addresses this by modifying the logic to test only the sense bit of the RA-word rather than the sense and strength bits. The second implication of the requirement is that Increase Rate RAs must also be capable of being reversed, if necessary. The need for such a capability became apparent as a result of certain FAA Technical Center flight tests in which the pilot did not respond to an altitude-crossing RA. As the threat executed its level-off maneuver, the RA strengthened to an Increase Rate in the crossing direction, and continued to be displayed until closest approach despite the fact that the threat was already level and the sense of the RA was in the direction of the threat. The solution to CRF 34 addresses this by deleting the test that excludes sense reversals in crossing encounters if an Increase Rate RA has been issued (PROCESS Reversal_check) and, in the event a sense reversal is selected, by clearing the track file variables and flags associated with any previously issued Increase Rate RA (PROCESS Reversal_modeling). The solution also resulted in a change to PROCESS Cross_through_check. Because this process would now be invoked only for noncrossing encounters, the test to determine if the encounter was crossing or noncrossing was deleted.

The second requirement was developed as a result of testing the operation of the v6.0 logic in multi-aircraft situations, but the pseudocode expression of it contained an error. That error, located in **PROCESS** Reversal_proj_check within the clause that considers sense reversal when ITF.OWN_CROSS is set, was the use of logical **OR** rather than **AND** to link two tests intended to restrict the operation of that logic. The solution to PTR 35 replaces the logical **OR** with **AND**.

The third requirement ensures consistency in the projections of threat altitude at closest approach used by the maneuver modeling, sense reversal, and crossing flag determination logics. In the v6.0 logic, the maneuver modeling equations use true TAU clipped by the appropriate value from P.TVPETBL. Clipping the TAU value used in projections is necessary because true TAU can become very large in slow-closure encounters (e.g., parallel approach or overtake situations). Using the full true TAU value in projections of altitude separation at closest approach can result in unnecessarily severe RAs because the projection falls within ALIM or shows the encounter geometry to be crossing, requiring an altitude-crossing RA. Because the projected separation at the clipped TAU value (for threats converging in altitude) may be larger than that at the full TAU value, the logic could initially issue an RA that is not as severe (either weaker or one that is noncrossing). A subsequent vertical avoidance maneuver by either aircraft could then change the original projection in such a way that a stronger RA might not be needed at all.

The effect of the third requirement on the crossing flag and reversal logics will result in a more accurate determination of whether the threat or own aircraft is responsible for the crossing geometry, as well as earlier detection of the need for a sense reversal. The solution to CRF 35 addresses this by incorporating the TAU clip mechanism in the pseudocode for **PROCESS** Reversal_check and **PROCESS** Crossing_flag_check.

The fourth requirement is addressed by the solution to PTR 28. This change corrects an inconsistency between the sense reversal and crossing flag determination logics in the applied definition of an altitude-crossing encounter. A delay of sense reversal in a noncrossing encounter that became crossing could occur if the altitude separation was exactly 100 ft. The definition used by PROCESS Crossing_flag_check meets the requirement: specifically, an altitude-crossing encounter is one in which a crossing sense RA has been chosen and own aircraft is currently separated from the threat by **at least** 100 ft vertically. The test within PROCESS Cross_through_check, which used **greater than** and **less than** in its comparisons, was modified to also comply.

2.4 INCREASE RATE RAs

2.4.1 Statement of Requirement

An RA to increase the vertical rate from 1500 fpm to 2500 fpm shall not be issued in an altitude-crossing encounter with a nonequipped threat if the threat is projected below own aircraft's current altitude when a Descend RA is displayed, or is projected above own aircraft's current altitude when a Climb RA is displayed.

2.4.2 Changes to the Increase Rate RA Logic

PTR 36 pertains.

The v6.0 logic did not comply with this requirement, and could issue an Increase Rate RA in a crossing encounter despite the fact that the intruder was already projected above or below own aircraft in the direction that own was heading. Furthermore, the v6.0 logic would not permit a sense reversal, despite the threat's projection, once an Increase Rate RA had been issued, a problem corrected by the logic change for CRF 34 described above.

With the solution to PTR 36, an Increase Rate RA will be inhibited in such instances and instead, a sense reversal will most likely occur on the next cycle. The reason that the logic did not reverse the RA sense on the current cycle is because the modeled response to the reversed-sense RA must not have overcome the intruder's projection based on its maximum rate bound. This will not continue to be the case as additional position data for the intruder is received, which confirms the occurrence of the level-off maneuver and causes a reduction in the intruder's vertical rate uncertainty bounds.

The solution to PTR 36 is implemented in PROCESS Increase_check, and incorporates additional tests on the sign of the projected altitude difference whenever an Increase Rate RA is being considered in an altitude-crossing encounter.

2.5 SENSE SELECTION WHEN OWN AIRCRAFT IS CLIMB-INHIBITED

2.5.1 Statement of Requirement

The TCAS logic shall bias against selection of the altitude-crossing sense when own aircraft is climb-inhibited.

2.5.2 Changes to Sense Selection When Own Aircraft is Climb-Inhibited

PTR 13 pertains.

The v6.0 sense selection logic incorporates an important bias against selecting the altitude-crossing Descend sense when own aircraft is climb-inhibited, the threat is currently below and is projected to remain below own aircraft at closest approach. However, if the threat is currently above but projected to be below own aircraft at closest approach, that same logic can bias toward selection of the altitude-crossing Climb sense. This is because the sense selection logic adds P.NOZCROSS (100 ft) to the projection for the Climb sense when own is climb-inhibited. In this instance, the logic will issue a Don't Descend RA (instead of Climb). The effect of the bias in this case is to select the sense that is projected to provide up to 100 ft less vertical separation, assuming the threat continues at its current vertical rate. If the threat slackens its rate so that it is still projected to cross, but within ALIM, the Don't Descend RA will continue to be displayed because the positive Climb RA is not able to be selected. If the threat actually levels-off before it crosses own altitude, the RA will reverse to Descend, albeit with reduced time available for response.

The solution to PTR 13 addresses this by restricting the application of the bias against crossing Descend RAs to encounters where the threat is no more than 100 ft above own and projected to pass substantially below at closest approach. In this instance, the threat is more likely to continue its descent rather than level-off. On the other hand, descending threats that are more than 100 ft away vertically and projected to cross are much more likely to level off than to continue their vertical rates. In this case, the bias is waived and if the projected separation for a Descend RA is greater than that for Don't Descend, the Descend RA will be selected. The solution to PTR 13 has been applied to PROCESS Alt_separation_test, PROCESS Evaluate_low_firmness_separation and PROCESS Select_sense.

2.6 NUISANCE ALARM FILTER (NAF)

2.6.1 Statement of Requirement

An RA shall be issued against any intruder that is within DMOD nautical miles in range and which satisfies the RA altitude threshold.

2.6.2 Changes to the NAF Logic and Minimum Range

PTR 34 pertains.

The NAF was developed to inhibit RAs against intruder aircraft that are well-separated in range and abeam of own aircraft at the time that they violate the RA altitude threshold. The reason that it was developed was to address concerns expressed by pilots participating in past operational evaluations of TCAS, that such RAs are unnecessary. The NAF operates by monitoring both the range of the intruder and the duration of time over which the true range TAU value (R/RDOT) has stopped declining. As long as the true TAU has been stabile or rising for at least three seconds by the time the intruder reaches the minimum range threshold of 1.5 nmi (P.NAFRANGE), and is not already considered a threat (i.e., has remained outside the RA altitude threshold), the range test will fail. Once an intruder has been qualified by the NAF, the logic will continue to inhibit issuing an RA, even if the intruder subsequently violates the altitude threshold. Assuming continued straight-line motion and that the intruder was initially at a range of 1.5 nmi at the time the RA was inhibited, the intruder will come no closer than 1.0 nmi. However, if the encounter geometry changes and the true TAU value resumes its decline, an RA will be issued immediately.

During tests involving encounters with slow-closure threats, it was discovered that the NAF did not meet the requirement stated above. Two issues with its operation surfaced: one being an error in the application of the NAF that would permit an intruder in a slow closure encounter to approach within DMOD nmi of own aircraft without generating an RA; the other being the fact that the minimum range threshold value would have allowed an intruder aircraft to pass within DMOD for sensitivity level 7 (1.1 nmi). The former problem was corrected by permitting the NAF to operate only if the intruder's range was greater than DMOD (PROCESS Range_test). The latter was corrected by assigning a value of 1.7 nmi to the minimum range threshold. Thus, under the assumption of straight-line motion, an intruder filtered by the NAF will come no closer than 1.1 nmi at the point of closest approach.

2.7 MODE S-EQUIPPED THREATS: HANDLING LOSS OF ALTITUDE AND DROPPED TRACKS

2.7.1 Statement of Requirement

When a Mode S-equipped threat stops reporting altitude or its track is dropped by surveillance, the CAS logic shall terminate the aircraft's threat status and shall expunge its Threat File entry. This shall also be performed for a Mode S threat that is TCAS-equipped, irrespective of the fact that it may have previously coordinated its maneuver intent.

2.7.2 Logic Changes to Address Track Drops and Loss of Altitude Involving Mode S-Equipped Threats

PTR 40 pertains.

During tests involving Mode S-equipped threats, it was discovered that the v6.0 logic does not adequately handle cases where the threat's track is dropped by surveillance or it stops reporting altitude. The problem arose because the TCAS MOPS specifies different surveillance requirements for Mode S-equipped aircraft than for Air Traffic Control Radar Beacon System (ATCRBS)-equipped aircraft. An ATCRBS threat that stops reporting altitude or stops replying altogether is coasted for six cycles and then dropped. During the coast period, its designation remains altitude-reporting. If it is reacquired, it is treated as a different track with its own designation (altitude-reporting or not). On the other hand, when a Mode S aircraft stops reporting altitude, its designation is changed by surveillance to be nonaltitude-reporting. If it resumes reporting altitude, its designation will once again change. Within the CAS logic, an intruder's loss of altitude-reporting capability is handled properly, its altitude track being discontinued and any supporting entries in structures and files being deleted. If an RA had been in progress against that aircraft, it is also removed. In addition, the Threat File (TF) entry is usually deleted, the exception being made for a TCAS-equipped threat that has coordinated its maneuver intent. Classification of the intruder as a continuing threat is also retained. It is the latter two logic operations that do not meet the requirement stated above. Later in the encounter, if the Mode S threat suddenly resumes reporting altitude, the logic will attempt to access the deleted TF entry, resulting in a run-time error.

The solution to PTR 40 addresses this by: (1) clearing the threat status indicator (ITF.KHIT) if the Mode S threat stops reporting altitude or its track is dropped by surveillance (TASK DETECT_CONFLICTS), and (2) retaining the TF entry for a TCAS-equipped threat that has coordinated its maneuver intent only if it has not stopped reporting altitude or had its track dropped by surveillance (PROCESS Update_threat_file_own).

2.8 RA DISPLAY LOGIC

2.8.1 Statement of Requirements

In a multi-aircraft encounter in which a corrective positive RA has been converted to a dual vertical speed limit RA, only the RA sense that requires a maneuver for compliance shall be designated as corrective.

An RA shall be indicated as being corrective if own aircraft's tracked vertical rate does not meet or exceed the goal rate for the selected RA. When comparing own's tracked vertical rate against the RA goal rate, hysteresis shall only be applied to determine if a preventive RA should be reclassified as corrective.

Neither the corrective climb nor corrective descend indication shall be set if no RA is being displayed.

A vertical rate of 2500 fpm shall be displayed for an Increase Rate RA. The displayed rate shall be retained as long as the need for an Increase Rate RA is indicated for any threat. When the Increase Rate RA is no longer needed but a positive RA is required, the magnitude of the displayed rate shall be the lesser of own aircraft's current vertical rate and 2500 fpm, and the greater of own aircraft's current vertical rate and 1500 fpm.

The value of the vertical rate to be displayed for any positive RA shall be explicitly specified in the data word sent to the RA display. The list of positive RAs includes: Climb, Descend, Crossing Climb, Crossing Descend, Maintain Climb, Maintain Descent, Increase Climb, and Increase Descent.

2.8.2 Changes to the RA Display Logic

PTRs 14, 21, 30, 31 and 32, and CRF 14 pertain.

During tests of the v6.0 logic, it was found that the corrective flags for both senses could be set if an initial corrective Climb or Descend RA was converted to Don't Climb/Don't Descend due to the presence of another threat above or below own aircraft. This could result in an ambiguous RA display, where the green "fly to" arc that is required for a corrective RA could be associated with the wrong sense. The solution to PTR 14 addressed this by having PROCESS Corrective_preventive_test explicitly clear the corrective flag for the opposite sense when it was setting that for the other.

When the value of hysteresis used by the logic in determining if an RA was corrective or preventive was increased from 150 fpm to 300 fpm in v6.0, it resulted in ambiguous displays and annunciations in situations where own's vertical rate was close to, but did not meet or exceed the RA goal rate. This was because the hysteresis was applied not only to preventive-to-corrective transitions, but also in the initial determination of RA type. As a result, some RAs that should have been designated corrective were actually classified as preventive, and were displayed having no green "fly to" arc and with a weaker aural annunciation ("Monitor Vertical Speed"). The solution to CRF 14 handled this by modifying PROCESS Corrective_preventive_test to not use hysteresis in the corrective-preventive determination for an initial RA, but to apply it only when transitioning from preventive to corrective.

Within the v6.0 logic, it is possible to set either one of the corrective flags despite the absence of a displayed RA. Tests within PROCESS Corrective_preventive_test check a minimum of three items in setting either corrective flag, including that the respective corrective flag is clear, no RA has been displayed on the previous cycle, and the magnitude of the tracked vertical rate is less than the RA goal rate. When no RA is being displayed, the corrective climb and descend flags have been cleared, the variables that retain the value of the RA from the previous cycle have been initialized to zero, and the goal rates have been set

to the signed value of P.HUGE. This leaves the goal rate/tracked rate comparison as the only discriminant that prevents setting either corrective flag. Therefore, if the magnitude of own's tracked vertical rate exceeds P.HUGE, either corrective flag can be set. The solution to PTR 30 addresses this by increasing the value of P.HUGE to 100,000 fpm, a value large enough to ensure that it will not be exceeded by contemporary aircraft.

It was discovered during tests involving multi-aircraft encounters that the displayed rate for an Increase Rate RA issued by the v6.0 logic could revert to the nominal rate of 1500 fpm on the next cycle, despite the requirement that a rate of 2500 fpm be displayed for a minimum of 10 seconds. An error was found in **PROCESS** Determine_goal_rate that would permit this to occur depending on the order of threats in the Threat File. The solution to PTR 21 handled this by always resetting the displayed rate to 2500 fpm on every cycle that an Increase Rate RA is indicated for any threat.

The second part of the fourth requirement listed above was developed as a result of flight test experience in which a pilot, responding to an Increase Rate RA, achieved a vertical speed in excess of 2500 fpm. During this time, the logic determined that the increase was no longer necessary, and selected the larger of 2500 fpm and own aircraft's current vertical rate, thereby requiring that the pilot maintain the higher rate. This was not in line with the intended function of the logic with respect to downgrading from Increase Rate RAs. The solution to PTR 32 ensures that the maximum rate that can be selected in this instance is 2500 fpm, with the minimum rate being the greater of the RA goal rate and own aircraft's tracked rate (**PROCESS** Determine_goal_rate).

Finally, because of the variety of positive RAs and the various vertical rates that they can specify, it was deemed necessary to require that those rates be placed in the rate-to-display subfield of ARINC 735 DITS Word 270, rather than relying on other variables and flags, and that the RA display must always check this subfield for the proper rate to display. This would ensure that the vertical rate being displayed for the RA always matches the modeled goal rate for the RA. The solution to PTR 31 modified the text in **PROCESS** Set_up_display_outputs for this purpose.

2.9 RA INHIBIT ALTITUDE AND AURAL INHIBIT ALTITUDE

2.9.1 Statement of Requirements

The TCAS logic shall inhibit all RAs when own aircraft is below 1000 ft AGL +/- 100 ft hysteresis.

TA aurals shall not be inhibited when RAs are able to be issued. Consequently, TA aurals shall be inhibited when own aircraft is below 1000 ft AGL +/- 100 ft hysteresis.

2.9.2 Parameter Changes to Address the RA Inhibit Altitude and Aural Inhibit Altitude

CRFs 48 and 75 pertain.

Data from the TCAS II Transition Program (TTP) indicate that RAs issued at low altitude have resulted in go-arounds, which have been disruptive to the orderly flow of traffic and have resulted in delays and economic impacts. Most of these RAs are unnecessary distractions, occurring during a high-workload phase of flight. At a meeting of the RTCA Pilot Working Group (PWG) held on 14 November 1991, it was recommended that the RA inhibit threshold be raised to be between 800–1100 ft AGL. A subsequent MITRE analysis (MITRE Memorandum No. F046-M-0711, 6 December 1991) suggested and provided rationale for using a value of 1000 ft AGL. Simulation replay of encounters derived from Dallas-Ft. Worth ground radar data showed that 6 percent (13 out of 230) of the RAs were eliminated by raising the RA-inhibit threshold to 1000 ft AGL. Examination of the simulation results showed that all the RAs eliminated were indeed unnecessary. The solution to CRF 48 raises the RA-inhibit threshold from 500 ft AGL +/- 100 ft hysteresis to 1000 ft AGL +/- 100 ft hysteresis.

In addition, the Descend RA inhibit threshold has not been altered, remaining at 1100 ft AGL +/- 100 ft hysteresis. The reason for its retention, rather than making it identical to the RA-inhibit threshold as suggested in the MITRE memorandum, is to provide a clearly defined altitude regime where a Descend RA will be converted to Don't Climb when own aircraft passes below the Descend-inhibit threshold. In this way, the pilot will receive aural and visual notification of the transition, which permits reduction of the descent rate, instead of merely having the Descend RA removed with no aural annunciation that maintenance of the descent rate is no longer required.

At the same meeting of the PWG, it was also decided that aural advisories for TAs must not be suppressed in altitude regimes where RAs can be given. Raising the aural inhibit threshold to be identical to the RA inhibit threshold was recommended. The rationale given included the desire to maintain a quiet cockpit under conditions of heavy workload on takeoff and landing; and that the regular scan of the traffic situation display by the pilot was sufficient to aid visual acquisition without the aural alert. The MITRE analysis (see memorandum referenced above) expands on this justification, again recommending that the threshold be 1000 ft AGL +/-100 ft hysteresis, which has been implemented as the solution to CRF 75.

2.10 REASONABLENESS CHECKS FOR OWN AIRCRAFT FINE ALTITUDE AND RADAR ALTITUDE

2.10.1 Statement of Requirement

Reasonableness checks shall be performed on all altitude data inputs for own aircraft, including data quantized to 100 ft (if used), finely quantized data, and data from the radio altimeter. These checks shall detect anomalous, inconsistent, or out-of-range data, and shall cause the data to be rejected and coasted for that cycle.

2.10.2 Changes to Incorporate Reasonableness Checks for Own Aircraft Fine Altitude and Radar Altitude

PTRs 46 and 49 pertain.

During the TTP, several issues were identified that were attributed to Collision Avoidance System (CAS) logic use of erroneous or inconsistent fine altitude data and radar altitude data for own aircraft. These included reports of Descend RAs being issued below the descend-inhibit altitude threshold, RAs being issued below the RA-inhibit altitude threshold, and RAs being issued against unobserved aircraft (with a known aircraft well above or below). TTP reports were also received concerning TAs being annunciated when own aircraft was below the aural-inhibit altitude threshold. It was recommended that reasonableness checks on altitude data inputs be incorporated in the CAS logic.

The 100 ft nonlinear vertical tracker specified within the v6.0 logic, whether used for tracking own aircraft altitude or intruder altitudes quantized to 100 ft, already incorporates reasonableness checks to reject and coast through erroneous or inconsistent data. Such checks were not originally required on fine altitude input data because the integrity of the sources was assumed to be much better. However, evidence exists to support the contention that data from these sources can be corrupted. During an evaluation of one manufacturer's TCAS systems conducted overseas, several questionable RAs occurred whose suspected cause was corruption of own fine altitude. Reasonableness checks were incorporated, and further instances of such RAs were no longer reported. In-flight recordings by TCAS systems have also revealed occasional inconsistencies in own altitude data. In addition, altitude data reported by aircraft having high-fidelity avionics, which were recorded by TCAS and ATC ground radar systems, have exhibited anomalous behavior that could either be the result of faulty encoding or some other systematic error. As a result of this evidence, the pseudocode was modified to strongly recommend the use of reasonableness checks on own fine altitude input (PTR 49; PROCESS Own_altitude_tracking). These checks will at least prevent TCAS from using faulty data for own aircraft tracking and from possibly generating unneeded TAs and RAs, although the altitude reported to other TCAS aircraft and ATC may still be corrupted.

Investigations of suspected causes also focused on possible radar altitude data corruption, but data taken by Bendix in flight tests of several jet transport aircraft showed good

However, a subsequent analysis of the CAS logic revealed that if the radar altitude data suddenly increased, whether erroneous or not, the logic could immediately select a higher Sensitivity Level enabling it to annunciate TAs and issue RAs, including Descend RAs. For this reason, the solution to PTR 46 incorporates in the pseudocode a recommendation for reasonableness checks on the radar altitude input value (PROCESS Radar_credibility_test).

For both solutions, some alternative methods for checking reasonableness are suggested, but the design is not specified because of input source variations from installation to installation. Instead, the TCAS manufacturers must design and certify their own algorithms tailored to the specific characteristics of each type of altitude source.

2.11 TRAFFIC ADVISORY THRESHOLD REDUCTIONS

2.11.1 Statement of Recommendations

While TAs are a required feature of the TCAS logic and minimum TA display requirements have been specified, the logic implementation contained in the TCAS MOPS is recommended rather than required. The TA altitude, range and TAU thresholds are also recommended, but not required. TAs are required as a precursor to RAs, and this requirement places certain restrictions on the TA thresholds relative to the RA thresholds. The duration of a TA prior to an RA, currently 15 seconds in the TCAS MOPS, is given as a range of possible values in the ICAO Aircraft Collision Avoidance System (ACAS) Standard and Recommended Practices (SARPs) (from 7.5 to 20 seconds before an RA). The TA altitude threshold is currently fixed by the TCAS MOPS and ACAS SARPs at 1200 ft relative altitude and is applicable to all altitude regimes.

The philosophy of flexibility afforded by the MOPS in the areas of TA logic and threshold design, has enabled manufacturers to adapt that logic to reduce the TA alert rate and provide for customer-desired features. Certain of these modifications have proven of substantial operational benefit and should be incorporated within the implementation recommended by the MOPS. For this reason, the following recommendations are made:

- TCAS should not issue TAs against legally separated Instrument Flight Rules (IFR) aircraft; the TA altitude threshold should increase as IFR separation increases.

- When own aircraft is below 5000 ft, the TA lead time prior to an RA should be 10 seconds rather than the 15 second TA lead time used at higher altitudes.

- TCAS should classify aircraft that are below 380 ft AGL +/-20 ft hysteresis as being on the ground.

- The minimum range threshold for TAs should not exceed the values specified within DMODTA_TBL.

2.11.2 Logic and Parameter Changes to Reduce the TA Thresholds

CRFs 15, 46, 73, 106 and 126 pertain.

The rationale for providing Traffic Advisories to the pilot includes the notion that a TA prepares the pilot for a possible subsequent RA by giving advance warning; that it enhances the pilot's ability to visually acquire aircraft because it displays range, altitude, and bearing of the intruder; and that it is a confidence-builder that shows that TCAS is working properly and providing correct information. The fact that TAs occur more frequently than RAs is appropriate for rapid confidence-building; however, the TA alert rate should not be so high as to constitute a nuisance.

During the TTP, many pilot reports have been received complaining of excessive numbers of unnecessary TAs being issued at low altitudes, even against aircraft that were either on or very close to the ground. Pilots also considered TAs issued against legally separated IFR aircraft to be unnecessary. Several changes to the TA thresholds and logic were therefore made to reduce the TA alert rate.

The first recommendation listed above was addressed by CRFs 15 and 126. The solution to CRF 126 resulted in further subdividing TCAS's vertical airspace map by creating two additional altitude layers below Flight Level (FL) 100. This subdivision provides greater flexibility in selecting both TA and RA altitude thresholds, enabling TCAS to better adapt to the terminal airspace. The solution to CRF 15 added the new TA altitude thresholds, which for altitudes up to FL300, have been reduced from 1200 ft relative altitude to 850 ft. Validation of the reduced TA altitude thresholds has come from experience. Flight tests conducted by Bendix in the Los Angeles basin using TCAS units modified to have the same altitude thresholds for TAs as for RAs, showed dramatic improvement in the TA alert rate. The TA thresholds were later increased to 850 ft to provide the proper lead time needed for the revised threat detection altitude thresholds (section 14), consistent with the lead time range required by the ACAS SARPs. Subsequent data collection efforts conducted by Delta airlines using TCAS units incorporating the 850 ft value, among other TA logic modifications, still showed a substantial improvement in the TA alert rate over the v6.0 logic, dropping the TA/RA ratio from 40:1 to 4:1.

The second recommendation was made by the PWG at a meeting held 14 November 1991. An original proposal to reduce the TA lead time from 15 seconds to five seconds across all sensitivity levels was not supported. The reasons cited included that the en route TA alert rate was not perceived to be a problem and that a five second lead time was not believed to be sufficient for situation assessment and visual acquisition. The reduction of the TA lead time to 10 seconds for sensitivity levels (SLs) 3 and 4 represents a compromise to help reduce the TA alert rate at low altitudes. The rationale given by the PWG for the 10 second value was to provide five seconds for the pilot to assess the displayed situation and five seconds for visual acquisition, and represents the operational judgment of the PWG based on experience using TCAS. Retention of the 15 second lead time at higher altitudes

deemed necessary to provide more time for visual acquisition because of the higher closure rates and longer ranges of intruder aircraft at the time the TA is issued.

The solution to CRF 46 addresses the second recommendation by reducing the TA Range TAU and Vertical TAU thresholds, as well as the DMODTA_TBL values for SL3 and SL4. These are given in the table shown below and affect table 7-1 of the TCAS II MOPS. The reason for also reducing the DMODTA_TBL values for SL3 and SL4 is as follows: the DMODTA_TBL values are set to the distance that an intruder aircraft would travel if it executed a standard rate turn (bank angle = 20 degrees) for the entire TA time. The new values represent the distance covered with a five second reduction in the TA TAU thresholds for those SLs. (Note: v6.04 includes logic modifications to use SL3 between 1000 ft AGL and 2350 ft AGL and sensitivity level 4 between 2350 ft AGL and FL50. The net result is that the SL4 regime has been moved up and replaces part of the v6.0 SL5 regime, and SL3 is now used in place of the v6.0 SL4 regime. The effect of these two changes is to reduce the RA TAU thresholds by five seconds over those used for v6.0 and likewise reduce the TA TAU thresholds by 10 seconds, when own aircraft is below 5000 ft).

VALUES OF SENSITIVITY LEVEL-DEPENDENT TRAFFIC ADVISORY PARAMETERS

Sensitivity Level	2	3	4	5	6	7
DMODTA_TBL (nmi)	.30	.33	.48	.75	1.0	1.3
TRTHRTA_TBL (s)	20	25	30	40	45	48
TVTHRTA_TBL (s)	20	25	30	40	45	48

The third recommendation was proposed as a result of TAs being issued against aircraft that were on or near the ground. Terrain fluctuations measured by TCAS when it is within 5 nmi of an airport can result in a changing estimate of the ground level. This estimate can sometimes be lower than the airport runway elevation. The use of a ground altitude allowance of 190 ft +/-10 ft by the v6.0 logic has proven to be insufficient in determining which aircraft are airborne or on the ground. This value has therefore been increased to 380 ft +/- 20 ft hysteresis. One TCAS manufacturer has already implemented the new threshold, with positive results reported by its airline customers. Simulations of logic performance against encounters derived from ARTS data have also resulted in elimination of unnecessary TAs and RAs against aircraft on the ground. The solution to CRF 73 implements the revised values of the relevant TCAS logic parameters.

The final recommendation was made by a TCAS manufacturer and the RTCA's TCAS II RWG as a result of reviews of the TA Range Test logic. It was discovered that the TA logic

Immediate Range Test was unnecessary. The Immediate Range Test was originally incorporated in the logic to retain an intruder aircraft on the TA display despite the fact that the intruder was no longer converging with own aircraft. The intruder was necessarily given TA status because early TCAS displays were event-driven (i.e., they did not display any intruder aircraft until one required a TA or RA). Most of today's TA displays are full-time displays and even though an intruder's display status may change, the display of traffic is not removed. In addition, regardless of whether the display is full-time or event-driven, the TCAS logic will retain an aircraft's TA display status for an additional eight seconds after it fails to qualify based on range and altitude.

The use of the Immediate Range Test with range thresholds that were larger than DMODTA, meant that any intruder within that range but still outside DMODTA, would qualify for a TA. At low altitude, where aircraft purposely fly close to one another (especially on parallel approach), the effect was to increase the TA alert rate. The application of this as the first test within PROCESS Traffic_range_test also caused subsequent tests using DMODTA to become dead code. Deletion of this test results in making the TA logic Range Test almost identical to the RA detection logic Range Test, especially in the use of DMODTA and DMOD, respectively. The solution to CRF 106 deletes all table and structure entries for RTHRTA, as well as the associated pseudocode in PROCESS traffic_range_test.

2.12 SENSITIVITY LEVEL SELECTION

2.12.1 Statement of Requirements

SL3 shall be used when own aircraft is between 1000 ft AGL +/- 100 ft and 2350 ft AGL +/- 200 ft.

SL4 shall be used when own aircraft is between 2350 ft AGL +/- 200 ft and FL50 +/- 500 ft.

The TCAS logic shall permit desensitization from any SL based on the value of radar altitude.

The TCAS logic shall select the SL that is proper for the altitude of the TCAS aircraft within one cycle.

2.12.2 Changes to the Sensitivity Level Selection Logic

CRFs 49, 87, and 88 pertain.

The first two requirements stated above address the need to reduce the TA and RA alert rates at altitudes below FL50, especially those issued when own aircraft is on parallel approach. In fact, most of the unnecessary TAs and RAs observed during the TTP have occurred on approach. Incorporating the ability to select SL3 instead of SL4 and SL4 instead of SL5 below FL50, results in a net reduction of five seconds in the RA TAU thresholds currently

used by the v6.0 logic, and a reduction of 10 seconds in the TA TAU thresholds. These modifications to the thresholds have been enabled because of better estimates of altimetry error and by accounting for the highly-structured nature of operations conducted near airports.

The vertical displacement achievable for SL3 is 211 ft, assuming a nominal pilot response to a positive RA (a five second delay followed by 0.25g acceleration to achieve 1500 fpm). Although this value is less than ALIM (300 ft in v6.04), it accounts for more than 2 sigma Root Sum Squared (RSS'd) altimetry and tracking bias errors (1 sigma = 90 ft). (Note that the 2 sigma value encompasses more than 95 percent of the distribution of errors.) Typically, more than 211 ft of vertical separation will be achieved by closest approach. Most encounter geometries involve some projected amount of vertical separation at closest approach due entirely to the threat's trajectory. The TCAS maneuver then builds on this to achieve adequate separation. As an added protective measure, TCAS can issue an RA to increase the vertical rate to 2500 fpm if the dynamics of the situation change so that own aircraft and the threat are projected to be within 200 ft vertically at closest approach. The increased rate over a 10-second period will generally result in at least 166 ft of additional vertical separation.

SL3 is active below 2150 ft AGL on approach, when own aircraft is within approximately 6 nmi of an airport (3 minutes away from landing) and is normally operating under strict ATC approach control procedures. On departure, SL3 is active up to an altitude of 2550 AGL, but the time spent in SL3 is much less than that on approach because the vertical rates are higher (about 1 minute at 1500 fpm). Tests of the revised CAS logic, using encounters derived from ground radar data at Dallas-Ft. Worth, show that the use of SL3 can eliminate approximately 70 percent of the RAs that were formerly issued by the v6.0 logic for encounters occurring between 1000 ft AGL and 2350 ft AGL. The net effect of raising the RA-inhibit altitude and the use of SL3 is the elimination of more than 75 percent of the RAs that used to be issued by the v6.0 logic in SL4.

The vertical displacement achievable for SL4 is 336 ft, assuming a nominal pilot response to a positive RA. This value exceeds ALIM (300 ft), accounting for more than 3 sigma RSS'd altimetry and tracking bias errors. (The 3 sigma value encompasses essentially 100 percent of the error distribution.)

In the v6.04 logic, SL4 is active between FL45 and 2150 ft AGL on approach and between 2550 ft AGL and FL55 on departure. This corresponds to the lower part of the SL5 regime of the v6.0 logic. Tests of the revised CAS logic show that the use of SL4 eliminates a significant, but smaller, percentage of RAs (compared with that for SL3), which were formerly issued by the v6.0 logic for encounters occurring between 2350 ft AGL and FL50.

The solution to CRF 49 modifies the sensitivity level selection logic (PROCESS Auto_SL) to permit selection of SL3, and adjusts the SL switching thresholds for SL2, SL4, and SL5 and adds new switching thresholds for SL3, to insert SL3 in place of the existing SL4 and raise SL4 to replace the lower part of the existing SL5 regime.

The last two requirements arose because of reviews of the TCAS logic conducted by the RTCA's TCAS II RWG.

With respect to the third requirement, it was observed that the v6.0 CAS logic lacked the ability to desensitize from SL6 based on radar altitude. While the ability to desensitize in this way from SL7, which is active above FL200, was determined to be unnecessary because no airports exist above that altitude, there are several airports worldwide that are at altitudes between FL100 and FL200. Using the v6.0 logic, TCAS would be unable to desensitize from SL6 prior to landing at La Paz, Bolivia for example. The solution to CRF 87 addresses this by incorporating checks on radar altitude within the logic to select each SL up to SL6 (PROCESS Auto_SL).

The fourth requirement resulted from an inquiry by the RWG as to the reason for the version 6.0 SL selection logic's ability to only change the SL by one level per cycle. The observation was made that if TCAS was restarted while own aircraft was airborne, it could take up to three seconds before TCAS would be operating at the proper SL based on altitude. An investigation of the logic algorithm was conducted by The MITRE Corporation, in which no requirement for this method of operation was found. As a result, the solution to CRF 88 modifies the CAS logic accordingly. Increasing the SL to the proper value will take place on a single cycle, while decreasing the SL will still be done one level per cycle. The reason for decreasing the SL by one level per cycle rather than immediately selecting the SL appropriate for the apparent altitude is to avoid sudden decreases in protection if a spurious radar altimeter value is input to the logic. This is likely to occur if the radar altimeter signal is reflected by dense clouds or the terrain below own aircraft suddenly drops off, and can also occur in the less likely case of an intruder aircraft passing directly below own.

In addition to the modifications described above, another change to the SL selection logic was made to permit fail-soft desensitization down to SL3 based solely on barometric altitude in the event that the radio altimeter fails. The selection algorithm used by the v6.0 logic only permits decreasing to SL5 in the event of radio altimeter failure. The change would have its greatest effect at airports located at sea level, permitting normal desensitization down to 1000 ft AGL, although RAs would not be inhibited below that altitude. This change extends the capability of the same logic that already exists in v6.0. (The ability of the logic to permit fail-soft desensitization, although available, is not currently used in today's TCAS units. Instead, they are designed to shut down when the radio altimeter fails.)

2.13 RA ALTITUDE THRESHOLD REDUCTIONS

2.13.1 Statement of Requirements

The altitude threshold for positive RAs (ALIM) shall be set to as small a value as possible to minimize resulting vertical displacements, and shall be set to a value large enough to compensate for 3-sigma (essentially 100 percent) of the RSS of own and intruder altimetry errors and vertical rate tracking bias error (approximated at 150 fpm). The threshold value

should be less than the legal vertical separation for IFR/Visual Flight Rules (VFR) traffic (500 ft) when TCAS is flying below FL200.

The value of the altitude threshold used for threat detection Altitude Threshold (ZTHR) shall not exceed ZMAX (see table below), and shall not be less than ALIM.

VALUES OF MAXIMUM ALTITUDE THRESHOLD FOR THREAT DETECTION

Altitude Band	**-6000 to 2550**	**2150 to 5500**	**4500 to 10500**	**9500 to 20500**	**19500 to 30500**	**29500 to 600,000**
ZTHR (ft)	750	750	750	750	850	950

The threshold values for ZTHR and ALIM shall be reduced or increased as needed based on the altitude regime of the TCAS aircraft. Provisions shall be made to permit added flexibility in selecting reduced thresholds when own aircraft is in the terminal area (below FL100).

2.13.2 Changes to Reduce the RA Altitude Thresholds

PTR 43 and CRFs 19 and 126 pertain.

Experience obtained during the TTP indicates that the RA alert rate in the terminal area is too high. RAs issued under high-workload conditions are distracting, and those that are corrective have resulted in unnecessary go-arounds and vertical displacements that are considered to be excessive. TCAS has also issued unnecessary corrective, positive RAs against VFR aircraft that are level and legally separated vertically. Furthermore, IFR aircraft that are slightly off altitude but otherwise flying according to the rules, have resulted in unneeded preventive RAs.

In addressing these concerns, it was necessary to further subdivide TCAS's vertical airspace map by creating two additional altitude layers below FL100 (CRF 126). This subdivision provides greater flexibility in selecting both TA and RA altitude thresholds, enabling TCAS to better adapt to the terminal airspace. The increased flexibility in threshold selection, as well as the new threshold values for ALIM and ZTHR, are given in the table below. The changes affect table 4-2 of the TCAS II MOPS. Also shown below are values for SENSFIRM (the minimum predicted vertical separation that is required for TCAS to select sense when there is low confidence in a threat's vertical rate), and ZTHRTA (the altitude threshold for TAs). The values of SENSFIRM remain unchanged over those used by the v6.0 logic. The values of ZTHRTA have been reduced as described in section 12.

VALUES OF ALTITUDE LAYER-DEPENDENT PARAMETERS

Bottom of Alt. Range (ft)	—6000	2150	4500	9500	19500	29500
Top of Altitude Range (ft)	2550	5500	10500	20500	30500	600,000
ALIM (ft)	300	300	350	400	600	700
SENSFIRM (ft)	200	200	200	240	400	480
ZTHR (ft)	600	600	600	600	700	800
ZTHR_TA (ft)	850	850	850	850	850	1200

CRF 19 originally suggested that ALIM be reduced from 400 ft to 300 ft when own aircraft was below 2500 ft AGL. This modification was intended to reduce the number of corrective RAs issued when TCAS was on approach, as well as decrease the magnitude of displacements that resulted from such RAs. The solution to this CRF was later expanded in scope to cover reductions in ALIM over the entire altitude regime, particularly below FL200. The new values of ALIM were designed primarily to reduce the number of corrective, positive RAs issued in encounters with VFR aircraft, at the same time meeting the requirements concerning allocations for altimetry and tracking bias errors. The reductions in ALIM were able to be made because recent studies showed better altimetry error distributions than had previously been assumed. With respect to the values of ALIM used at high altitude, a slight reduction of 40 ft was implemented in the values used above FL200 to provide a more consistent difference between ZTHRTA, ZTHR, and ALIM. Studies of altimetry error at high altitudes have shown error distributions that are favorable toward reductions in those TCAS altitude thresholds.

The table below shows the RSS'd allocations for altimetry and tracking bias errors by sensitivity level, along with the new values for ALIM. It can be seen across all sensitivity levels that the new values for ALIM are at least three times the value of the RSS'd errors. In addition, a safety study of the risk due to altimetry error using the new values of ALIM showed a slight, but acceptable increase.

The reductions in the values of the threat detection altitude threshold (ZTHR) were originally made as part of the solution to PTR 43 (the VTT, section 15). The proposed values were designed to work in concert with reduced vertical TAU thresholds to eliminate unnecessary noncrossing RAs issued against threats that were likely to level off 1000 ft away vertically. The values were optimized by varying them in steps of 25 ft from 750 ft down to 600 ft, inclusive, in thousands of simulated encounters with intruder aircraft that leveled off

Sensitivity Level	TAU Threshold (sec)	Altitude (Kft)	RSS Altimetry & Tracking Errs (ft)	ALIM (ft)
3	15	1	89	300
3	15	2.35	90	300
4	20	5	96	300
5	25	10	111	350
6	30	15	126	400
6	30	20	135	400
7	35	25	151	600
7	35	30	157	600
7	35	35	161	700

approximately 1000 ft away vertically from the TCAS aircraft. The encounters were based upon a model of European airspace that was derived from ground radar data. This model was used to obtain preliminary estimates of system safety using the VTT logic, as well as estimates of operational benefits. The results of the simulations with the VTT logic showed that as the value of ZTHR decreased, about 50 percent of the preventive RAs were eliminated. A smaller decrease in the number of corrective RAs was also observed. The numbers of both preventive and corrective RAs appeared to approach an asymptote with decreasing ZTHR, and as a result, 600 ft was chosen as a reasonable value. The values of ZTHR used at high altitude were then determined by decreasing the original ones by 150 ft (the difference between 750 ft and 600 ft).

The reductions in the values of ZTHR result in elimination of many RAs against threats that level off approximately 1000 ft away, and make the logic tolerant of overshoots of up to 400 ft. A significant number of preventive RAs have also been eliminated in encounters with level aircraft at lower altitudes, especially in parallel approach geometries. Preventive RAs are also expected to be eliminated in certain crossing situations, where own or intruder aircraft with a vertical rate is now projected to cross the altitude of the other aircraft outside the reduced ZTHR.

2.14 VERTICAL THRESHOLD TEST (VTT)

2.14.1 Statement of Requirement

TCAS shall not issue positive, corrective (displacement-inducing), noncrossing RAs against climbing or descending intruder aircraft that are currently separated vertically by more than ZTHR as they are likely to level off outside ZTHR. The reduced time-to-coaltitude thresholds shown below shall be used in encounters where own and the intruder are separated vertically by more than ZTHR, and either the magnitude of own aircraft's vertical rate is 600 fpm or less, or own's vertical rate is the same sign as the intruder's, but is less in magnitude.

Sensitivity Level	3	4	5	6	7
P.TVVTT_TBL	15	18	20	22	30

2.14.2 Changes to Incorporate the VTT

PTR 43 pertains.

During the TTP, it has been observed that noncrossing RAs are being issued against threats that level off at cardinal altitudes above or below the TCAS aircraft, resulting in displacement of the TCAS aircraft from its clearance, often by larger-than-expected amounts. The displacements, greater than 500 ft, are considered operationally disruptive to the ATC system. These RAs are being issued because the time-to-coaltitude drops below the threshold when the intruder is still a significant distance from its level-off altitude.

The requirement to eliminate these RAs as stated above is necessarily broad, lacking specific details characterizing intruder aircraft that are "likely to level off." In designing the solution to PTR 43, therefore, consideration was given to likely intruder rates, timing of level-off maneuvers to achieve IFR separation, typical accelerations used by autopilots, and maneuver intent. These considerations were based on operational experience, expert knowledge, and a realistic characterization of the airspace environment using encounters derived from European and U.S. ground radar data. Trade-offs in the design were made in order to balance the desire for fewer alarms against a resulting higher level of risk.

[The solution to PTR 43 has undergone several revisions and improvements since its original design. That design, called the Variable Vertical Threshold (VVT), was described in a working paper (WG2 WP/319) presented at a meeting of the SSR Improvements and Collision Avoidance Systems Panel (SICASP) Working Group 2 in October 1991. It involved dynamically setting the vertical threshold based upon a fixed minimum (ZTHR) to which was added a variable component (10 percent of the rate of convergence in altitude).

The values for ZTHR were also reduced by 150 ft to account for the added 10 percent factor. (That is, the dynamic threshold would provide at least the same 1500 fpm or less.) The 10 percent factor was originally derived from a Rule-of-Thumb used by pilots of military aircraft—specifically, a maneuver to level off at a particular altitude should begin when the aircraft is at a vertical distance equivalent to at least 10 percent of its vertical rate from that altitude. This equated to a vertical acceleration of about 0.15g. (Maneuver commanded by transport category autopilot systems are typically conducted at 0.05g and, as a result, are begun much sooner. The use of the 10 percent factor, therefore allowed some latitude for the TCAS vertical tracker to recognize that a maneuver was underway.) Finally, a minimum vertical TAU threshold of 15 seconds was imposed to ensure that vertical separation of at least 200 ft could be achieved in a predicted collision geometry.

Concerns about the short warning time (15 seconds) were expressed both by the RTCA SC-147 PWG and SICASP Working Group 2. It was suggested that the vertical TAU threshold be made large enough to provide approximately ALIM separation in a collision geometry (say, 20 seconds or so) and that the full TAU thresholds be used in encounters where own aircraft had the higher vertical rate to permit operation of the "Take ALIM" test. The "Take ALIM" test avoids selection of a crossing maneuver providing at least ALIM separation would be achieved, even though the separation provided by crossing would be greater.

Because of these concerns, the original VVT logic and thresholds were modified. Instead of using a single vertical TAU threshold of 15 seconds, a table of values indexed by sensitivity level is used (see table above). These values are appended to table 5-1 of the TCAS II MOPS. The values, for the most part, will result in ALIM separation at closest approach. The variable component of the threshold was also eliminated because the use of longer warning times provides protection and operational benefits that are equivalent to the original logic. The reduced values of ZTHR, on the other hand, were retained. The revised solution to PTR 43 is now called the VTT.]

The VTT vertical TAU thresholds are applied only in certain encounter geometries. Those geometries are restricted to situations where own aircraft is level, as well as cases where own and the intruder have vertical rates of the same sign and the magnitude of own's rate is less than that of the intruder. In all other encounter geometries, the full vertical TAU threshold is used. This includes encounters where the rates are opposite in sign, as well as situations where the vertical rates are the same sign but the magnitude of own's rate is greater than the intruder's (per SICASP Working Group 2's recommendation). The reason for the restriction with respect to opposite rate situations is that the "Take ALIM" logic would not be as effective, with more crossing RAs resulting. System safety simulations have shown an unacceptable increase in risk if the VTT, with its reduced warning time, is permitted to operate in this type of encounter geometry. The reason for the latter restriction is that the "Take ALIM" test would most likely result in a noncrossing RA, which may be considered a beneficial reinforcement of an intended level-off maneuver by own aircraft. The selection of the appropriate vertical TAU threshold for the encounter geometry is handled by modifications to **PROCESS** Set_detection_parameters.

The VTT vertical TAU thresholds are invoked for intruders which are outside of ZTHR and converging in altitude. They delay threat detection by several seconds over the vertical TAU thresholds normally used, in deference to a possible level-off maneuver by the intruder. The TAU thresholds used in SL4, SL5, SL6, and SL7 all provide separation equivalent to 3-sigma RSS'd altimetry and tracking bias errors (nearly ALIM) in a collision geometry, assuming the nominal pilot response (five seconds delay followed by 0.25g acceleration to achieve 1500 fpm).

The threshold used for SL3, at 15 seconds, is the same as that used for the range TAU threshold and will result in 211 ft of vertical displacement. Although this value is less than

ALIM (300 ft in v6.04), it accounts for more than 2 sigma RSS'd altimetry and tracking bias errors (1 sigma = 90 ft). (Note that the 2 sigma value encompasses more than 95 percent of the distribution of errors.) Typically, more than 211 ft of vertical separation will be achieved by closest approach. Most encounter geometries are not projected to be coaltitude, involving some projected amount of vertical separation at closest approach due entirely to the threat's trajectory. The TCAS maneuver then builds on this to achieve adequate separation, weakening or strengthening the RA as needed. As an added protective measure, TCAS can issue an RA to increase the vertical rate to 2500 fpm if the dynamics of the situation change so that own aircraft and the threat are projected to be within 200 ft vertically at closest approach.

The effectiveness of the VTT has been shown in preliminary safety simulations using a model derived from European ground radar data and in safety simulations using a model derived from U.S. ground radar data. Confirmation of benefit has also been obtained from simulations of actual encounters extracted from the ground radar data. In these simulations, the VTT eliminated more than 80 percent of RAs caused by the IFR level-off geometry, while alerting as necessary when the intruder level-off was late or did not occur at all. System safety simulations show that while the risk of a TCAS-induced Near Mid-Air Collision (NMAC) does increase, it does so by a small amount (less than 1 percent) that is considered acceptable given the extraordinary operational benefit associated with this change.

SECTION 3

SUMMARY

In the sections above, v6.04 to the TCAS logic has been described, justification of its need has been given, and the rationale behind the design of various logic and parameter changes has been presented. The package of pseudocode replacement pages and revised threshold tables was provided to RTCA SC-147 on 1 April 1992. The existing TCAS MOPS bench tests have been revised and additional bench tests have been created. These will be provided to SC-147 in August 1992.

APPENDIX B

LOGIC FEATURES TESTED

The following logic features were tested in the verification of v6.04:

- Initialization and Control
  - Startup
  - Test for Automatic Sensitivity Level Selection
  - Altitude-Dependent Parameters
    - ALIM
    - ZTHR
    - TAUR
    - TAUV
    - VTT TAUV
    - DMOD
  - Operation of Aural Alarm and Aural Annunciations
    - Aural inhibit
    - Altitude Crossing
    - Maintain Rate

- Single Threat Resolution
  - Sense Selection in Level Flight
  - Sense Selection in Non-Level Flight
  - Advisory Selection
  - Inhibition of Advisory
    - Due to low firmness
    - Due to low altitude
  - Advisory Evaluation
    - Weakening
    - Strengthening
    - Sense Reversal
    - Increase Rate
  - Identification of Threats on the Ground
  - Limitations Due to Aircraft Performance
    - Climb inhibit
    - Increase Climb inhibit
    - Descend inhibit
    - Increase Descend inhibit
  - Clear of Conflict Indication
  - Elimination of Nuisance Alarms

- Multiple Threat Resolution
  - Conversion of Negative to Positive
  - Conversion of Positive to Negative
  - Reversal of "Don't Care" Cases
  - Simultaneous New "Don't Care" Cases
  - Clear of Conflict Indication
  - Reversal of Dual Negative (Composite) RAs

APPENDIX C

DESCRIPTION OF OPERATIONS AT ARTS DATA LOCATIONS

BURBANK

Burbank Airport, Burbank California, also known as Burbank-Glendale-Pasadena, consists of two intersecting runways, 15/33 (6885x150) and 8/26 (6074x150). Runway 8 is the only runway with instrument approaches and also due to surrounding terrain, it is the runway used most for turbojet traffic. Surrounding airports that are also in the Burbank Terminal Radar Approach Control Facilities (TRACON) are Van Nuys and Whiteman. The approaches for runway 8 at Burbank pass directly over Van Nuys at an altitude of approximately 600 feet above the Van Nuys traffic pattern. This is the cause of the majority of the TAs and RAs in this area.

COAST

The major airports within the Coast TRACON are Long Beach and John Wayne–Orange County (Santa Ana) Airports. Long Beach has five runways, two north/south oriented, two east/west oriented, and the longest diagonally, northwest/southeast, intersecting the other four runways. 16R/34L (4470x75) is parallel to and spaced approximately 2300 feet from 16L/34R (4267x75). The two east/west parallels are 7L/25R (6192x200) and 7R/25L (5420x150) which are approximately 3200 feet apart. These four runways intersect each other to form a box with runway 12/30 (10000x150) diagonally crossing all the runways. Runway 30 is the only runway with an instrument approach and is used for the larger turbojet traffic. This is a high noise sensitivity area and due to the sizes of the runways, the lack of instrument approaches, and the abundance of VFR routes, the traffic at this airport tends to be smaller VFR aircraft.

John Wayne–Orange County (Santa Ana) Airport has two closely spaced parallels. 1L/19R (5700x150) is spaced approximately 500 feet from 1R/19L (2887x75). 1L and 19R have instrument approaches and are used for larger aircraft. When running simultaneous visual approaches to these closely spaced runways, a high rate of TAs and RAs can occur.

Other airports of concern in this data set are Fullerton Municipal, Tustin (MCAS), and El Toro (MCAS).

DENVER

The Denver/Stapleton International Airport consists of six runways. Three are parallel north/south oriented and three are parallel east/west oriented. The three north/south runways are 18/36 (7750x100), 17R/35L (11500x150), and 17L/35R (12000x200). 17R/35L and 17L/35R are spaced approximately 1600 feet apart. The east/west runways include 7/25 (4871x75), 8L/26R (8599x150), and 8R/26L (10004x150). These three runways are spaced

within 1000 feet of each other. All runways, except for 7/25 and 17R have defined instrument approaches.

Other airports in the area include Jeffco, Front Range, and Centennial.

DALLAS/FT. WORTH

Dallas/Ft. Worth International has two sets of north/south oriented parallel runways and two northwest/southeast runways, one to the east of the parallels and one to the west. The first set of parallels are 18R/36L (11388x150), 18L/36R (11387x200), and 18S/36S (4000x100). 18R/36L is 1250 feet west of 18L/36R and 18S/36S is 800 feet to the east of 18L/36R. A mile to the east of these runways are 17R/35L (11388x200) and 17L/35R (11387x150) which are spaced approximately 1200 feet apart. Runway 13L/31R (9000x200) is east of 17L/35R and 13R/31L (9300x150) is to the west of 18R/36L. All runways except for 13L, 36R, and 35L have instrument approaches.

Other airports in this TRACON are Dallas Love, Addison, Goode, NAS Dallas (Hensley Field), and Grand Prairie. Grand Prairie has extensive helicopter traffic due to a helicopter training area. The instrument approaches for 36L and 35R put the aircraft 3000 feet over this airport which could raise the potential for RAs and TAs.

LOS ANGELES

Los Angeles International has two sets of closely spaced east/west oriented parallel runways. 24R/6L (8925x150) is approximately 700 feet from 24L/6R (10285x150). 7L/25R (12091x150) is approximately 800 feet from 7R/25L (11096x200). There is greater than 4500 feet separating the sets of parallels. All runways have instrument approaches and simultaneous instrument approaches can be ran for Instrument Landing System (ILS) 25L and 24L/R or ILS 25L and 24L/R. Visuals approaches can be run simultaneously to both runways in each set of closely spaced parallels.

MEMPHIS

Memphis International has one set of north/south oriented parallel runways and a single east/west runway. 18R/36L (9319x150) is spaced 3500 feet from 18L/36R (8400x150) and 9/27 (8936x150) is located just north of the parallels. All the runways have instrument approaches.

Other airports in this area include Olive Branch, West Memphis, Isle-A-Port, and Gen. Dewitt Spain. The latter are two small airports along the Mississippi River to the Northwest of Memphis.

MINNEAPOLIS/ST. PAUL

Minneapolis/St. Paul International Airport consists of three runways. A set of parallels, 11L/29R (8200x150) and 11R/29L (10000x200), and 4/22 (8256x150) which crosses both parallels. All runways have instrument approaches and simultaneous operations on intersecting runways are made.

Other airports of in this TRACON include St. Paul–Downtown (Holman) and South St. Paul Municipal (Fleming). Both are within ten miles and east of the Minneapolis/St. Paul International.

NEW YORK

The New York TRACON has John F. Kennedy International, La Guardia, and Newark International Airports all within 20 miles of each other. There is a high degree of interaction and coordination between the operations at these airports along with smaller airports in the area, such as Teterboro. There is also a VFR corridor along the Hudson River that could be a source of TAs and RAs.

John F. Kennedy International has five runways, two sets of intersecting parallels and a single smaller runway to the northeast of the parallels. 13R/31L (14572x150) and 13L/31R (10000x150) are separated by approximately 6500 feet. 4L/22R (11351x150) and 4R/22L (8400x150) are spaced 3000 feet apart. 4L/22R crosses both 13R/31L and 13L/31R near the southeast ends of those runways. 14/32 (2560x75) is the runway off the northeast end of 4L/22R. There are instrument approaches to all but runways 14 and 32. There are helicopter operations and simultaneous instrument approaches to intersecting runways.

La Guardia has two intersecting runways, 4/22 (7000x150) and 13/31 (7000x150). All runways have instrument approaches. When landing runway 13 the aircraft will be approximately 2800 feet over Teterboro airport. Landing on runway 4 has to be coordinated with approaches to 13L/R at Kennedy. Helicopter operations, as well as simultaneous operations on intersecting runways are also performed at this airport.

Newark has three runways, 4L/22R (8200x150) spaced 1000 feet and parallel to 4R/22L (9300x150), and 11/29 (6800x150) which is above the north ends of the parallels. There are instrument approaches to 4R/22L and 4L/22R and simultaneous operations on intersecting runways. Approaches to 4R/L place the aircraft approximately 1700 feet above Linden Airport which may raise the occurrence of TAs and RAs.

ONTARIO

Ontario TRACON is in the Los Angeles basin and is located to the east of LAX and the Los Angeles TRACON. Ontario International has two parallel runways spaced approximately 750 feet apart, 8L/26R (12200x150) and 8R/26L (10200x150). There are instrument approaches to all runways except 8R.

Other airports in this TRACON include Riverside Municipal, Chino, Cable, Brackett, and Rialto Municipal (Miro). These airports cater mainly to VFR traffic.

SEATTLE

The Seattle TRACON has two major airports in it, Seattle-Tacoma International and Seattle Boeing Fld/King County International.

Seattle-Tacoma International has two parallel runways, 16R/34L (9425x150) and 16L/34R (11900x150) spaced 800 feet apart. There are instrument approaches to all runways. Approaches to 16L/R put the aircraft 1800 feet over Boeing Fld/King County International. This is the cause of the majority of the TAs and RAs in this area.

Boeing Fld/King County International also has two closely spaced parallels. 13R/31L (10001x200) is 500 feet apart from 13L/31R (3710x100). 13R/31L has instrument approaches. The traffic pattern altitude for 13L/31R is 1000 feet and for 13R/31L it is 800 feet.

ST. LOUIS

St. Louis International (Lambert) has five runways. Three are parallel to each other, 12R/30L (11019x200) spaced 1250 feet from 12L/30R (9003x150) which is spaced 500 feet from 13/31 (6289x75). The other two runways are 17/35 (3008x75) and 6/24 (7602x150). The ILS 30R and the LDA/DME 30L are authorized simultaneously as well as the ILS 12R and the LDA/DME 12L. Simultaneous operations on intersecting runways is also authorized. RAs and TAs may be generated due to the flightpaths of aircraft on the parallel and converging approaches. Also, the approach for runway 6 will put an aircraft approximately 2300 feet over Arrowhead Airport which may cause TAs and RAs.

APPENDIX D

INTEROPERABILITY ANALYSIS OF VERSION 6.0 AND VERSION 6.04

ANALYSIS OF INTEROPERABILITY OF TCAS VERSION 6.0 SYSTEMS WITH THOSE HAVING VERSION 6.04

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17 June 1992

SECTION 1

INTRODUCTION

The version 6.04 (v6.04) change package includes all modifications to the Traffic Alert and Collision Avoidance System II (TCAS II) logic since version 6.0 (v6.0). Those changes have been designed in response to Problem/Trouble Reports (PTRs) and Change Request Forms (CRFs) issued against the v6.0 logic, many resulting from operational experience gained during the TCAS II Transition Program (TTP), and others resulting from detailed tests performed by the TCAS manufacturers. Certain changes have already been released by the FAA and implemented by the TCAS manufacturers in subsequent system installations. These include changes to the TCAS modeling logic when own aircraft is climb- or descend-inhibited, as well as minor modifications related to Resolution Advisory (RA) sense reversals and handling of Mode S threats that lose altitude-reporting capability. Because different versions of the TCAS logic will exist in the U.S. fleet (i.e., systems with the original logic, those with the modeling logic corrections, and those having v6.04), the ability of those systems to interact and perform effectively with one another was investigated. The results of that analysis are presented below.

SECTION 2

INTEROPERABILITY OF VERSION 6.0 WITH VERSION 6.04

Of the logic modifications contained in v6.04, only five groups of changes may have an effect on interoperability, primarily in the areas of conflict detection and resolution. These are the following:

- Use of Sensitivity Levels (SLs) 3 and 4 in altitude bands that are different from those of v6.0
- Use of a raised RA-inhibit altitude
- Use of reduced values for the positive RA altitude threshold (ALIM)
- Corrections to the RA response modeling logic when own aircraft is climb- or descend-inhibited, and
- Incorporation of the Vertical Threshold Test (VTT) with its reduced threat detection altitude thresholds and vertical TAU thresholds

With respect to the mechanics of coordination between two TCAS systems, nothing has been changed. RF messages and their contents are unaffected. The coordination logic itself is also unaffected in that the first TCAS to detect the conflict and select sense transmits its intent, thereby constraining the choice of sense by the other. Tiebreaking in the event of simultaneous coordination is also unaffected, as is the detection rule that the higher sensitivity level of the conflicting aircraft be used as the SL for the encounter, thereby ensuring that both aircraft use the same TAU thresholds.

2.1 REVISED APPLICATION OF SENSITIVITY LEVELS

Version 6.04 changes the low-altitude sensitivity level selection scheme by replacing the former SL4 regime with SL3, and inserting SL4 in place of the former SL5 regime below 5000 ft. This means that a TCAS aircraft with v6.04 will be operating with RA TAU thresholds that are five seconds less than those used in v6.0 when it is below 5000 ft. In a conflict involving the different versions, however, the detection rule stated above ensures that both aircraft will operate at the higher SL for the entire encounter, from the time that surveillance initiates track on the intruder until the track is dropped.

2.2 REVISED RA-INHIBIT ALTITUDE

Version 6.04 raises the RA-inhibit altitude from 500 ft (±100 ft hysteresis) to 1000 ft (±100 ft hysteresis).

In a conflict occurring above 1000 ft AGL between aircraft having the different logic versions, RAs are enabled in both, and detection, resolution and coordination will take place as usual. Any differences in conflict detection between the two versions will either be due to the reduced vertical TAU thresholds (paragraph 2.5.1) or the reduced threat detection altitude threshold (paragraph 2.5.2); and any differences in the selection of RA sense or strength will be due to the use of reduced values of ALIM (paragraph 2.3) and, if own aircraft is performance-inhibited, the corrected modeling logic (paragraph 2.4). The coordination process remains unaffected.

The following paragraphs refer to cases where one of the TCAS aircraft in a conflict is RA-inhibited for the duration of the encounter, or becomes either RA-enabled or RA-inhibited as the encounter progresses.

If an aircraft having either v6.0 or 6.04 is below its respective RA-inhibit threshold at the time of conflict detection by an RA-enabled aircraft (with either version), the RA-inhibited aircraft is treated as if it were an unequipped threat, and resolution is accomplished by the RA-enabled aircraft. As long as the RA-inhibited aircraft remains below the threshold, the RA-enabled aircraft will not attempt to coordinate maneuver intent because the threat is treated as unequipped. Sense reversals against the RA-inhibited threat are also permitted.

On the other hand, if the RA-inhibited aircraft becomes RA-enabled (either automatically based on altitude, or because of SL commands from the pilot or a Mode S ground sensor) during an encounter in which the other TCAS aircraft had already selected an RA, it might not receive the other's intent before it selects its own RA. This is because the change in its status from TA-only to RA-enabled will not be recognized by the other TCAS aircraft until that aircraft's surveillance subsystem receives the information and passes it along to its collision avoidance logic. In the meantime, the TCAS logic in the newly RA-enabled aircraft could have already selected an RA and begun transmitting its maneuver intent to the other. Once the newly RA-enabled aircraft is recognized as TCAS-equipped, the other TCAS will begin transmission of its maneuver intent as well. The exchanged intent messages are then compared and, if the RAs are incompatible, a reversal will occur in the aircraft having the higher Mode S ID. Such reversals should be very rare because, even in the absence of initial maneuver coordination, selection of noncomplementary RA senses is very unlikely, given the encounter geometry and the extensive use of biases and delays against selecting altitude-crossing RAs.

The method of operation described above is true for both logic versions and is the subject of PTR 47, which proposes that TCAS transmit intent information to other TCAS-equipped threats that report that they are in TA-only mode. This would ensure that the complementary sense RA would be selected immediately by that threat in the event it became RA-enabled during the encounter. PTR 47 is slated for resolution as part of Change 7.0 to the TCAS II logic.

Finally, in either logic version, if an RA is in progress at the time TCAS becomes RA-inhibited, the RA will be removed; and if the threat is RA-enabled, a closeout coordination sequence will be sent. The cockpit display in the RA-inhibited aircraft will continue to show the other aircraft as a Traffic Advisory. If an RA had also been issued in the other aircraft, it will continue to be displayed as long as the RA-inhibited aircraft remains a threat. As above, sense reversals would also be permitted against the newly RA-inhibited threat because it is treated as unequipped.

2.3 REVISED VALUES OF ALIM

Version 6.04 reduces the values of ALIM overall, most significantly at altitudes below FL200. The result is that fewer displacement-inducing RAs will be issued and, for encounters projected to be within ALIM at closest approach, less vertical separation will be required in response to such an RA. In addition, even fewer crossing RAs will be selected because of the operation of "Take ALIM" logic, which chooses the noncrossing sense if it provides ALIM separation, even though that provided by crossing would be greater. None of these characteristics have an effect on TCAS-TCAS coordination. Only the RA strength and resulting excursion may be different in an encounter involving the different versions.

2.4 CORRECTIONS TO THE TCAS MODELING LOGIC WHEN OWN AIRCRAFT IS CLIMB- OR DESCEND-INHIBITED

Version 6.04 introduces corrections to the TCAS RA response modeling logic to properly handle cases when own aircraft is either climb- or descend-inhibited. The nature of the problem is described in MITRE Memorandum F046-M-0775. The effect on the inter-operability of TCAS units having the corrected v6.04 logic with those that have v6.0 is that fewer altitude-crossing RAs will be selected by the v6.04 logic. Regardless of which aircraft chooses its RA first, the coordination logic will ensure that the maneuvers are compatible.

2.5 THE VERTICAL THRESHOLD TEST (VTT)

Version 6.04 incorporates a VTT that has been designed to reduce the number of noncrossing RAs issued against aircraft that level off close to 1000 ft above or below own aircraft. It accomplishes this by using somewhat reduced vertical TAU thresholds and reduced values of the threat detection altitude threshold (ZTHR).

2.5.1 The Effect of Reduced Vertical TAU Thresholds

The reduced vertical TAU thresholds are only applied in situations where own aircraft is level (i.e., the magnitude of own's vertical rate is no greater than 600 fpm), or has a vertical rate that is the same sign as the intruder's, but is less in magnitude. The result is that the

v6.04 logic will delay threat declaration for several seconds beyond that of v6.0 against vertically converging intruders, providing an important additional time to detect a level-off.

If the v6.04 aircraft is level, other delays in threat declaration, which are contained in both versions, will apply once the reduced vertical TAU threshold is violated. These include the test that causes a level TCAS aircraft to delay up to three cycles waiting for an intent message from a climbing or descending TCAS-equipped threat that is projected to cross altitudes (the Altitude-rate test). [This delay is invoked because the nonlevel aircraft is predisposed to select a noncrossing RA, whereas the level aircraft would most likely select the crossing.] The other delay is called the "600-ft Rule," which results in the level TCAS aircraft delaying selection of a crossing RA until the threat is within 600 ft vertically. These tests, coupled with the reduced vertical TAU thresholds in the v6.04 aircraft, provide additional time for a nonlevel aircraft with the v6.0 logic to detect the conflict first and select a noncrossing RA.

If the encounter geometry is such that the reduced vertical TAU thresholds cannot be used (the aircraft have opposite-sign rates or own aircraft is not level and the magnitude of its vertical rate exceeds that of the intruder), v6.04 selects the same vertical TAU thresholds as v6.0.

2.5.2 The Effect of the Reduced Threat Detection Altitude Threshold

The reduced values of the threat detection altitude threshold (ZTHR) have also been analyzed as to their effect on interoperability. In particular, the differences in the values of ZTHR used by two TCAS aircraft with the different logic versions may have an effect on whether one or both aircraft detect the conflict. This effect is described below, using thresholds for the altitude regime extending from 0 to 20,000 ft.

In order to illustrate the analysis of interoperability between the v6.04 logic, which uses 600 ft as the value for ZTHR, and the v6.0 logic, which uses 750 ft, the encounter geometries that are possible were divided into four classes, as follows:

- Those in which the aircraft are currently separated vertically by 600 ft or less and are predicted to remain within 600 ft at closest approach;
- Those in which either the current vertical separation is less than 750 ft and the projected separation at closest approach is between 600 and 750 ft;
- Those in which the current vertical separation is between 600 and 750 ft and the projected vertical separation is less than 600 ft; and

- Those in which the current vertical separation is outside 750 ft, both aircraft are converging in altitude, and are either predicted to be within 600 ft or between 600 and 750 ft at closest approach.

The first three classes cover the cases where the current and projected vertical positions are within 750 ft. The last class covers all other cases where current vertical separation exceeds 750 ft.

2.5.2.1 Current and Projected Vertical Separation are Within 600 ft

For encounters in which the two aircraft are already within and projected to be within 600 ft vertically (figure 1), the different logics operate in the same way that the v6.0 logic does now. That is, if either logic operating in the nonlevel aircraft detects the conflict first an RA will be selected immediately and an intent message will be sent to the other TCAS aircraft. In the level aircraft, regardless of the encounter geometry (crossing or noncrossing), the RA may be delayed by the Altitude-rate test if the nonlevel TCAS aircraft has not yet sent its intent. (Note that because the aircraft in this instance are already within 600 ft vertically, the other bias against selection of an altitude-crossing RA, the "600-ft Rule", is not a factor.)

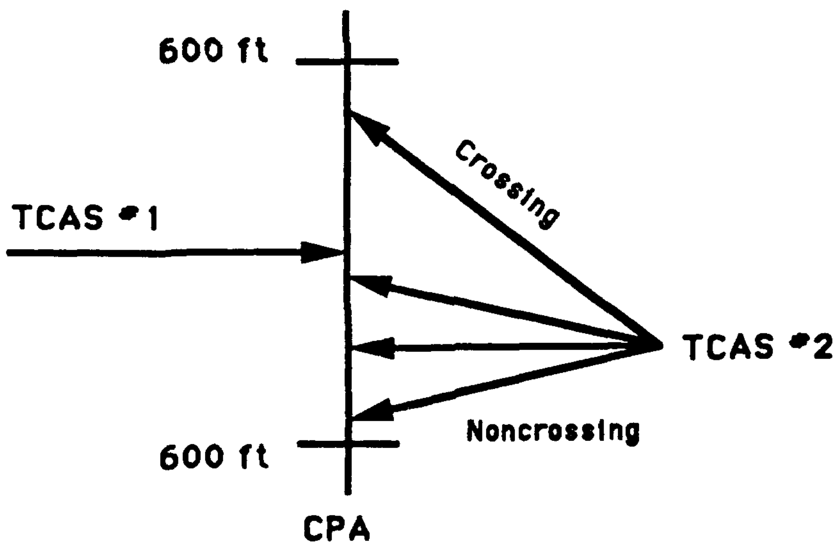

Figure 1: TCAS (with V6.0 or 6.4) Currently Within and Predicted Within 600 ft Vertically

2.5.2.2 Current Vertical Separation is Less Than 750 ft; Projected Vertical Separation is Between 600 and 750 ft

For encounter geometries in which the two aircraft are within 750 ft vertically and are projected to be between 600 and 750 ft away vertically at closest approach (figure 2), no RA will be issued by the new logic, but an RA will be issued by the v6.0 logic: immediately, if the encounter is noncrossing; or possibly delayed by the Altitude-rate test and the "600-ft Rule" if the v6.0 aircraft is level and the encounter is crossing.

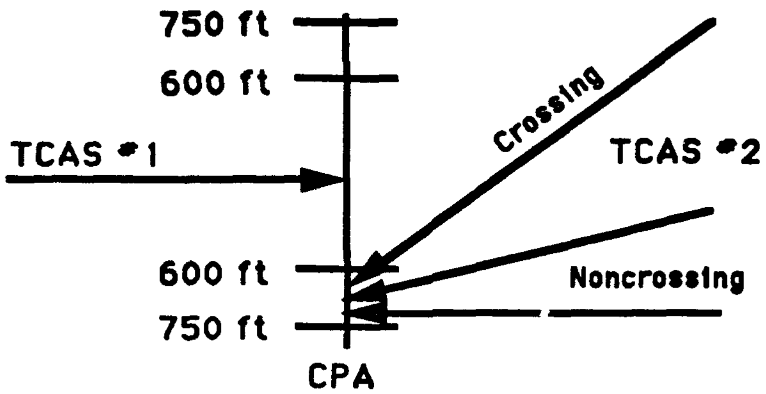

Figure 2: Currently Within 750 ft, Projected Between 600 and 750 ft

2.5.2.3 Current Vertical Separation is Between 600 and 750 ft; Projected Vertical Separation is Less Than 600 ft

For encounter geometries in which the two aircraft are between 600 and 750 ft away vertically, are projected to be within 600 ft at closest approach, and continue as projected (figure 3), an RA will be issued by both logics. It will be issued immediately in the nonlevel aircraft regardless of the encounter geometry (crossing or noncrossing) and the logic version used.

The level aircraft, on the other hand, presents a special case. If the level aircraft has v6.04, threat declaration will be delayed by the VTT in noncrossing geometries until either the new vertical TAU threshold or the new ZTHR is crossed. In crossing encounters, the RA in the level aircraft will also be delayed by the Altitude-rate test and the "600-ft Rule" (unless an intent was received from the nonlevel aircraft). (Also refer to the paragraph discussing figure 6.)

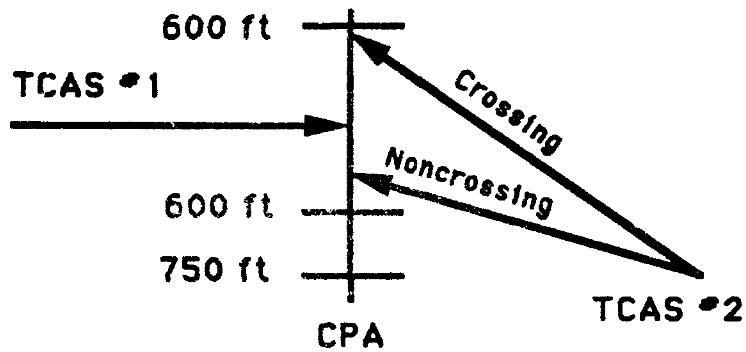

Figure 3: Between 600 and 750 ft, Projected Within 600 ft

It is important to note that if the two aircraft have vertical rates that are opposite in sign and the magnitude of those rates exceed 600 fpm, the VTT logic is not used. In these instances, the v6.04 logic will alert either because the relative altitude threshold (600 ft) has been crossed or because the time-to-coaltitude dropped below the normal threshold for the given sensitivity level.

2.5.2.4 Converging in Altitude; Current Vertical Separation Greater Than 750 ft

Encounter geometries in which the two aircraft are converging in altitude, but are currently outside 750 ft, can be subdivided into three cases: those in which neither aircraft is level, but have vertical rates of opposite sign (figure 4); those in which neither aircraft is level, but have vertical rates of the same sign (figure 5); and those in which one of the aircraft is level (figure 6). Differences between crossing and noncrossing situations are considered where appropriate.

2.5.2.4.1 Converging in Altitude; Opposite-sign Vertical Rates

In the first case, shown in figures 4a and b, the VTT logic is not used, and the only difference in operation will be due to the different values of ZTHR. The type of encounter geometry (crossing or noncrossing) is also not a factor. Furthermore, because the aircraft are not level, neither the Altitude-rate test nor the "600-ft Rule" will be used to bias against selection of an altitude-crossing RA. However, the "Take ALIM" logic is still effective in this type of encounter and, as a result, a noncrossing RA is almost always selected, even if the initial geometry was crossing.

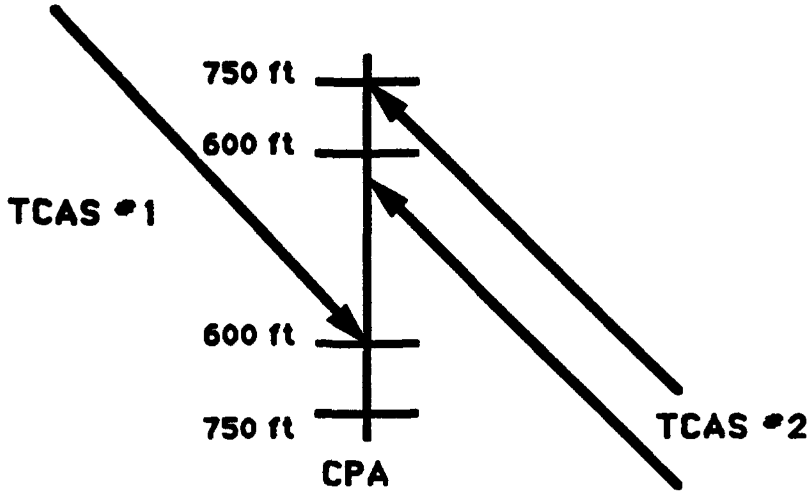

Figure 4a: Crossing, Vertical Rates Opposite in Sign

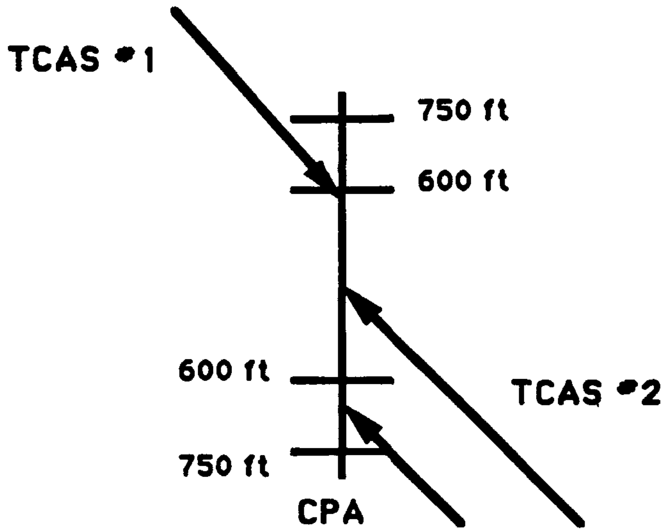

Figure 4b: Noncrossing, Vertical Rates Opposite in Sign

If the two aircraft are projected to be within 600 ft at closest approach, an RA will be issued in both aircraft when the time-to-coaltitude drops below the full vertical TAU threshold. If, on the other hand, the two aircraft are projected to be between 600 and 750 ft vertically at closest approach when the time-to-coaltitude drops below the threshold, an RA will be issued by the v6.0 TCAS, but none will occur in the aircraft having v6.04.

2.5.2.4.2 Converging in Altitude; Same-sign Vertical Rates

In the second case, shown in figures 5a and b, the type of encounter geometry (crossing or noncrossing) is also not a factor. Nor does it matter which of the TCAS-equipped aircraft illustrated in figure 4 incorporate the VTT or v6.0 logic. (Although for the purposes of the discussion here, it is convenient to label TCAS #1 as having the VTT logic). As above, because the aircraft are not level, neither the Altitude-rate test nor the

"600-ft Rule" are used to bias against selecting an altitude-crossing RA. However, the "Take ALIM" test used by both logic versions may still prevent some altitude crossings if the threat's projection is sufficiently close to own's current altitude. Safety simulations have shown that the effectiveness of the "Take ALIM" test is greatest when the full vertical TAU thresholds are used. This is the case for v6.0 operation in all high vertical closure encounter geometries. Version 6.04 also uses the full TAU thresholds if own aircraft is not level or has a same-sign vertical rate greater in magnitude than the intruder's.

In other encounter geometries (own aircraft is level or has a vertical rate whose magnitude is less than that of the intruder's), v6.04 uses reduced vertical TAU thresholds, while

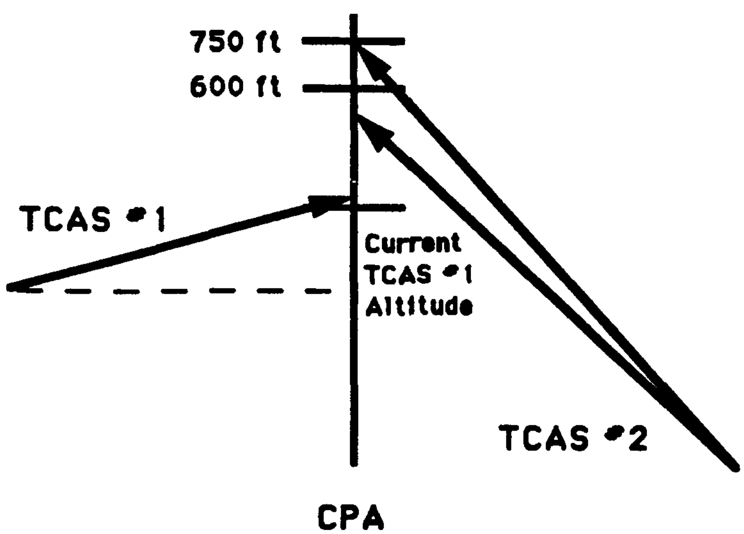

Figure 5a: Crossing, Vertical Rates of Same Sign

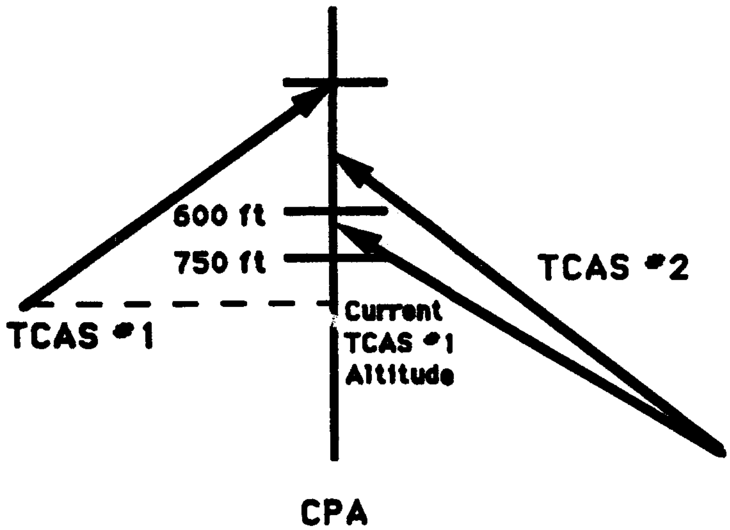

Figure 5b: Noncrossing, Vertical Rates of Same Sign

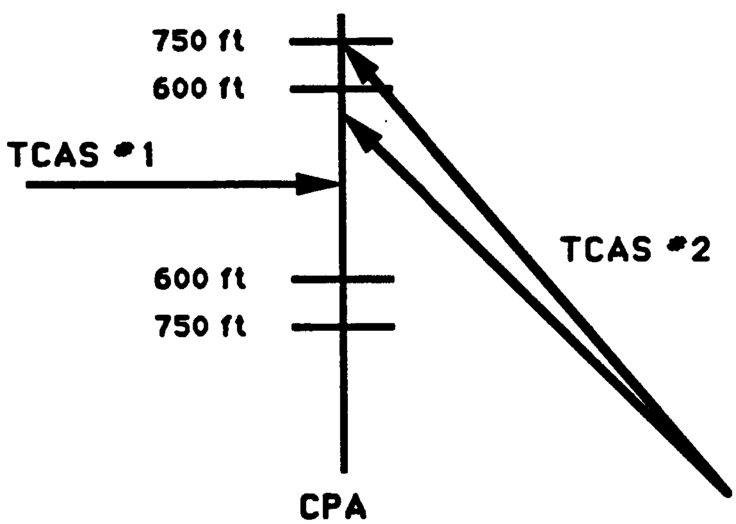

Figure 6a: Crossing, One Aircraft Level

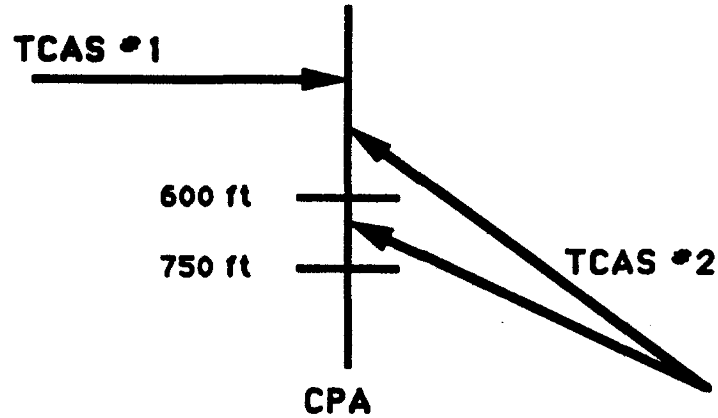

Figure 6b: Noncrossing, One Aircraft Level

Version 6.0 does not. If the two aircraft are projected to be within 750 ft at closest approach, an RA will be issued by the v6.0 logic when the time-to-coaltitude drops below the full TAU threshold. The VTT logic, on the other hand, will not issue an RA at all if the projection is greater than 600 ft, and otherwise will delay the RA until either the new ZTHR or the reduced vertical TAU threshold is crossed. Another reason that the aircraft with the VTT logic might not receive an RA is if the other aircraft, having been issued a noncrossing RA, starts its response so that it does not cross the VTT threshold of the first.

2.5.2.4.3 Converging in Altitude; One Aircraft Level

In the last case, shown in figures 6a and b, the type of encounter geometry is indeed a factor for the level aircraft. If that aircraft is using v6.04 with the VTT, the reduced vertical TAU thresholds will be selected. The delay in threat detection that they provide over those used by v6.0 allows for the possibility of a level-off maneuver by the v6.0 intruder, which is using the full vertical TAU thresholds. In addition, in the event that the vertical TAU threshold is violated and the encounter geometry is crossing, threat declaration will also be delayed by the Altitude-rate test and the "600-ft Rule" if an intent has not yet been received, whether the level aircraft is equipped with v6.0 or 6.04.

Regardless of the encounter geometry or whether TCAS #1 or #2 is equipped with the VTT logic, no RA will be issued in the aircraft with the new logic if the other aircraft is projected to be between 600 and 750 ft away at closest approach. However, an RA will be issued by the v6.0 logic if the projection is less than 750 ft and the time-to-coaltitude drops below the vertical TAU threshold. Furthermore, in encounters where the projection is less than 600 ft, a level aircraft with the VTT logic, using the reduced vertical TAU thresholds, will delay

threat detection over v6.0, while a nonlevel aircraft with the VTT logic, using the full vertical TAU thresholds, will detect the conflict at the same time as v6.0.

In crossing geometries where the threat is projected between 600 and 750 ft away as shown in figure 6a, the fact that the v6.0 logic recognizes the conflict, while the new logic does not, may have implications for the effectiveness of the Altitude-rate test. In this instance, the v6.0 logic in the level aircraft will delay threat detection for up to three seconds while it waits for an intent that never comes, and will ultimately select an altitude-crossing RA when the other aircraft approaches within 600 ft vertically. Had the v6.04 logic in the climbing aircraft (TCAS #2) recognized the conflict, it would most likely have chosen a noncrossing RA and co-ordinated first.

The fact that the v6.0 logic in the level aircraft will select a crossing rather than noncrossing RA, must be kept in perspective. It is important to note that the climbing aircraft's vertical rate must be in excess of 2000 fpm at the time it crosses the 600 ft threshold of the level aircraft, and therefore is not considered likely to level off so as to thwart the crossing RA. In addition, if the nonlevel aircraft subsequently slackened its vertical rate so that it was projected within ZTHR, it would be constrained to select a crossing RA because the intent of the other aircraft had already been coordinated. Of course, if the v6.0 aircraft is the one with the vertical rate, the RA will most likely be noncrossing owing to the operation of the "Take ALIM" logic.

SECTION 3

SUMMARY OF INTEROPERABILITY ANALYSIS FOR THE VERSION 6.04 LOGIC

From the discussions above, it can be seen that the aircraft with v6.04 will receive an immediate benefit compared with the performance of v6.0, in that v6.04 will delay threat declaration long enough to preclude issuing an RA in many instances. Version 6.04 will also result in fewer displacement-inducing RAs, along with reduced magnitudes of displacement. In addition, v6.04 will select fewer altitude-crossing RAs primarily because the reductions in ALIM make the "Take ALIM" logic even more effective.

In conflicts between aircraft having the different versions, coordination ensures that the selected maneuvers, whether crossing or noncrossing, are compatible. The first aircraft to select sense constrains the sense of the other. In some encounters involving a level v6.0 aircraft and a nonlevel v6.04 aircraft that does not detect the conflict, a crossing-sense RA in the level aircraft may be delayed for up to three cycles by the Altitude-rate test. No RA will be issued in the nonlevel aircraft if it maintains its vertical rate; the level aircraft will receive a preventive RA. On the other hand, if the nonlevel aircraft reduces its vertical rate so that it is projected to be within ZTHR at closest approach, an RA to maintain its rate will be issued, and the preventive RA in the level aircraft will become corrective.

GLOSSARY

ACAS	Aircraft Collision Avoidance System
AGL	Above Ground Level
ALIM	Altitude Limit
ARTS	Automated Radar Terminal System
ATC	Air Traffic Control
ATCRBS	Air Traffic Control Radar Beacon System
CAS	Collision Avoidance System
CPA	Closest Point of Approach
CRF	Change Request Form
FAA	Federal Aviation Administration
FL	Flight Level
HMD	Horizontal Miss Distance
IFR	Instrument Flight Rules
ILS	Instrument Landing System
MOPS	Minimum Operational Performance Standards
NAF	Nuisance Alarm Filter
NMAC	Near Mid-Air Collision
PCs	Personal Computers
PTR	Problem/Trouble Report
PWG	Pilot Working Group
RA	Resolution Advisory
RSS	Root Sum Square
RTCA	(formerly, Radio Technical Commission for Aeronautics)
RWG	Requirements Working Group
SARPS	Standard and Recommended Practices
SICASP	SSR Improvements and Collision Avoidance Systems Panel
SC	Special Committee
SL	Sensitivity Level
T&E	Test and Evaluation
TA	Traffic Advisory
TCAS II	Traffic Alert and Collision Avoidance System II
TF	Threat File

TRACON	Terminal Radar Approach Control Facilities
TTP	TCAS II Transition Program
V6.0	Version 6.0
V6.04	Version 6.04
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions
VMD	Vertical Miss Distance
VTT	Vertical Threshold Test
VVT	Variable Vertical Threshold
ZTHR	Altitude Threshold